# The Australian and New Zealand Journal of Surgery

**APRIL, 1948.**

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References to articles and books should be carefully checked. In a reference the following information should be given without any abbreviation: initials of author, surname of author, full title of article, name of journal, volume, full date (month, day and year), number of the first page of the article. If a reference is made to an abstract of a paper, the name of the original journal, together with that of the journal in which the abstract has appeared, should be given, with full date in each instance.

When illustrations are required, good photographic prints on glossy gaslight paper should be submitted. Line drawings, charts, graphs and so forth should be drawn on thick white paper in indian ink. Authors who are not accustomed to prepare drawings of this kind, are invited to seek the advice of the Editor if they are in any doubt as to the correct procedure. Skiagrams can be reproduced satisfactorily only if good prints or negatives are available.

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THE AUSTRALIAN AND NEW ZEALAND JOURNAL OF SURGERY

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# CONTROLLED RESPIRATION AND CURARE IN MODERN SURGERY.[1]

By R. H. ORTON,

*Anæsthetist to the Thoracic Surgical Unit, Alfred Hospital, Melbourne.*

TONIGHT I am very conscious of the honour that the Executive Committee of the Royal Australasian College of Surgeons has conferred upon me by asking me to address this gathering. But even more important than this honour is the indication it gives of the growing appreciation that a high standard of anæsthesia is needed before the problems of present-day surgery can be solved.

## HISTORICAL.

Controlled respiration and the use of curare have developed along two separate lines; but today these have blended, so that one cannot be considered without the other. Whilst controlled respiration developed as the result of thoracic surgery and the use of curare of abdominal surgery, now they are used together in both, though the reasons for their use differ somewhat in the two cases.

Controlled respiration was first described in 1934 by the Californian anæsthetist Guedel,[1] in a paper entitled "Ether Apnœas". During abdominal operations under ether anæsthesia he used periods of apnœa to provide the surgeon with better access to the upper part of the abdomen. In 1938, Crafoord,[2] the Scandinavian thoracic surgeon, published a paper on pneumonectomy, in which he described an elaborate machine for administering anæsthetics during operations involving the use of an open thorax. This equipment he took to America in 1940,[3] where it was received with wonder and admiration; but few copied his method, as it required the presence in the theatre of a mechanical engineer to work the apparatus. Then, in 1941, the London anæsthetist Nosworthy[4] read a paper before the Royal Society of Medicine on the use of controlled respiration and cyclopropane which stands as a masterpiece of description and lucid thinking. Since the publication of that paper little has been added to our knowledge of controlled respiration.

Descriptions of the actions of curare were first brought to civilization by Sir Walter Raleigh in 1595, and its properties were investigated by the eminent French physiologist Claude Bernard[5] in 1844; but it was not until 1938 that Gill[6] in California prepared pure extracts free from dangerous side effects. He gave to the world a curare preparation which could be

[1] Accepted for publication on June 19, 1947.

used with predictable results and put the use of the drug on a sound basis. The first reports of its clinical use in surgery came from Griffith,[7] of Canada, in 1942, and from that time onwards numerous articles appeared on the value of the substance for producing muscular relaxation.

As the years passed it became apparent that curare was capable of producing profound respiratory depression and even arrest of respiration. In February, 1946, Harroun and Hathaway[8] published a paper on the use of curare in thoracic surgery. They deliberately abolished voluntary respiration with massive doses of curare and maintained respiration by periodic pressure on the bag of the anæsthetic machine. In the following month Gray and Halton[9] read a paper in London on the use of "Pentothal" and d-tubocurarine chloride in thoracic surgery. In both these cases the use of curare was combined with the method of controlled respiration.

The stage has now been reached where it is realized that curare can give adequate abdominal relaxation only at the price of respiratory depression,

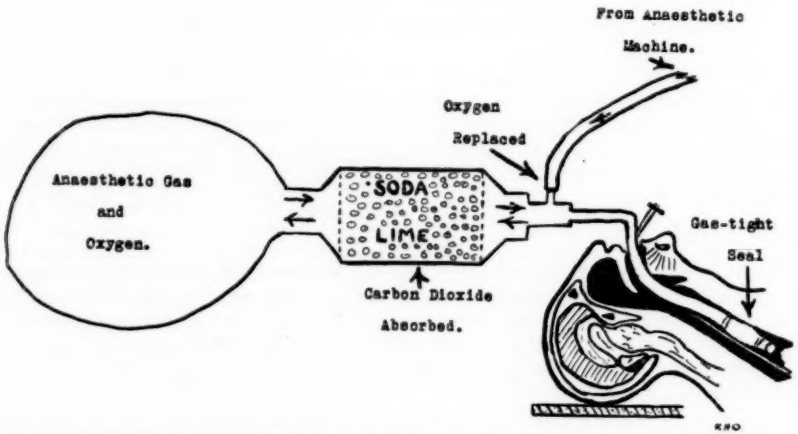


FIGURE I. Closed-system anæsthesia. Carbon dioxide absorption technique (diagrammatic).

so that a new phase has appeared in the use of the drug. In thoracic surgery it has been found[10] that curare is an efficient means of abolishing bronchial reflexes, so that it is possible to use light anæsthesia and, by means of controlled respiration, to maintain normal respiratory exchange. In abdominal surgery light anæsthesia can be employed, adequate muscular relaxation obtained, and by means of controlled respiration the respiratory depression that must result from the use of the drug can be overcome.

## THE CARBON DIOXIDE ABSORPTION METHOD OF ANÆSTHESIA.

Before I pass to a discussion of controlled respiration it is necessary to describe briefly the principle of carbon dioxide absorption technique as used in anæsthesia. This method of administration forms the basis of all means commonly employed for obtaining control of the respiration. With the carbon dioxide absorption technique the patient is placed in a closed system and shut off from all communication between his lungs and the outside air. In Figure I he is depicted with an endotracheal catheter *in situ*, the lungs being sealed from the air by a balloon inflated in the trachea. The patient is compelled to breathe entirely through the catheter, which is connected

to a canister filled with soda-lime. This substance has the property of absorbing carbon dioxide exhaled by the patient. At the distal end of the canister is a rubber reservoir bag, and any pressure applied to this by the anæsthetist is transmitted to the lungs of the patient. As the patient breathes he uses oxygen, and this is replaced from the cylinders of the gas machine via an inlet tube inserted between the catheter and the soda-lime canister. Theoretically, once the patient has been anæsthetized, no further anæsthetic drug should be needed, as this is exhaled unchanged and rebreathed with the next inhalation. In practice there is some loss from the skin, the operative wound, and through the rubber bag, so that a small quantity has to be added from time to time.

If during inhalation the anæsthetist applies pressure to the bag of the anæsthetic machine, the tidal respiration is increased in volume. On exhalation, which is a passive process, this increased volume passes through the soda-lime and a greater quantity of carbon dioxide is removed from the body than during normal respiration. As this periodic pressure is continued by the anæsthetist the level of the carbon dioxide in the blood is lowered until finally it falls below the threshold of the respiratory centre and spontaneous respiration ceases. In spite of the apnœa the anæsthetist continues the intermittent pressure on the bag and efficient respiratory exchange is maintained. Upon this principle controlled respiration is founded.

## CONTROLLED RESPIRATION.

Controlled respiration may be defined as a form of anæsthesia in which a state of apnœa is produced and the respiratory exchanges are maintained by periodic inflation of the lungs throughout the duration of anæsthesia. Certain advantages have been claimed for controlled respiration. In thoracic surgery its use prevents mediastinal "flap" and paradoxical respiration, two of the major hazards of open thorax surgery. These will be discussed more fully later. It maintains respiratory exchanges in the presence of an open thorax. From the viewpoint of the thoracic surgeon one of the greatest advantages is that it provides him with more satisfactory operating conditions. The immobile diaphragm and quiet respiration render surgery much easier than do the conditions under voluntary respiration. In abdominal surgery controlled respiration again provides quieter conditions for surgery than are possible without its use. It allows the employment, without damage to the patient, of methods of anæsthesia which produce respiratory depression, and it makes possible prolonged surgery without exhaustion of the patient.

Two main objections have been made against the use of controlled respiration. Firstly, Beecher[11] stated that it caused alkalosis by washing out carbon dioxide from the blood. The early forms of control, such as suggested by Crafoord, did cause alkalosis; but modern methods do not. The second objection was that it abolished the respiratory signs of anæsthesia. This is most certainly true; but today it would not be suggested that endotracheal anæsthesia should not be employed in cerebral surgery because the eyes are not available for the observation of the ocular signs of anæsthesia. The anæsthetist using controlled respiration must learn to do without the visual signs of respiration, just as he has learnt to do without eye reflexes.

It is necessary now to consider some of the physiological problems of respiration, first with a closed and then with an open thorax. With the closed thorax it is usual to speak of a negative pressure within the pleural cavity; but this is only a potential space and, therefore, can have no negative pressure within it. The forces that are present in this region are those of

the elastic recoil of the lung tissues, which rise from five millimetres of mercury on expiration to ten millimetres on inspiration. These forces are balanced by equal but opposite forces which prevent the separation of the visceral and parietal pleuræ. When one pleural cavity is opened widely, the resultant disturbance to the patient depends upon whether or not the mediastinal tissues have been rendered fixed by inflammatory changes. If the tissues are rigid it would appear at first sight as though little change is produced. It must be remembered, however, that the whole of the tidal exchange now must be accommodated in the one lung, so that the range of excursion of the respiratory muscles is increased to double that present before the chest is opened. This is reflected in the violent movement of the diaphragm and the bringing into play of the various accessory muscles of respiration. If, on the other hand, the mediastinum is mobile two important changes occur (Figure II). Since the mediastinum is subjected to changing pressures on the side of the closed thorax it will swing from side to side with respiration. As the patient inhales, the mediastinum will "flap" towards

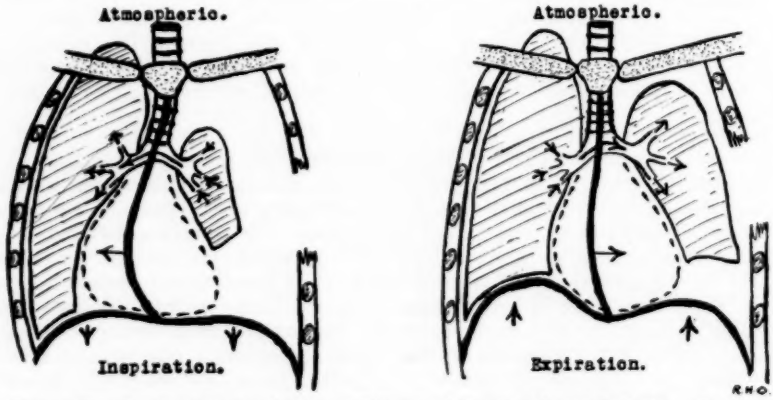


FIGURE II. Spontaneous respiration. Mediastinal "flap" and paradoxical respiration.

the side of the closed thorax, thus nullifying the expansion of the thoracic cage. On expiration, the mediastinum will move towards the side of the open thorax so that there will be little reduction in the volume of the lung. Most of the respiratory effort will be wasted in swinging the mediastinum from side to side and will produce inadequate respiratory exchange. In addition, on expiration, instead of the air being expelled up the trachea, it is forced into the lung on the side of the open thorax, which lung is partly expanded. On inspiration this air is sucked back into the opposite lung and in extreme cases little tidal air passes up and down the trachea. This condition is spoken of as "paradoxical respiration", as the lung under observation by the surgeon expands during expiration and contracts during inspiration, which is the reverse of the normal mechanism. With a mobile mediastinum the combination of "flap" and paradoxical respiration may embarrass the patient to such an extent that surgery may become impossible.

When controlled respiration is used a state of apnœa is produced and voluntary contraction of the diaphragm ceases (Figure III). The anæsthetist applies to the lung a pressure of approximately five millimetres of mercury during the inspiratory phase of the artificial respiration. During expiration the pressure is removed and the elastic recoil of the lung tissues expels the gases. With a mobile mediastinum to-and-fro movement still takes place

and there is still some expansion of the lung on the side of the open thorax. The mediastinal "flap" is now, however, a benefit to the patient, as it allows adequate expansion of the lung on the side of the closed thorax. This expansion is further aided by the passive descent of the diaphragm, which is pushed downwards by the expanding lung. The lung, which is under observation through the open thorax, still expands and contracts with respiration; but the movements are no longer paradoxical. As compared with voluntary respiration, control gives efficient exchange of carbon dioxide and oxygen to an extent not possible without its use.

It has long been taught by physiologists that the so-called negative pressure in the chest is an important factor in the venous return of blood to the heart and hence in the maintenance of blood pressure. With controlled respiration this negative pressure is converted to positive during "inspiration" and it might be expected that the cardiac output would be reduced. In fact it is found that there is no such fall when control is initiated. With an open

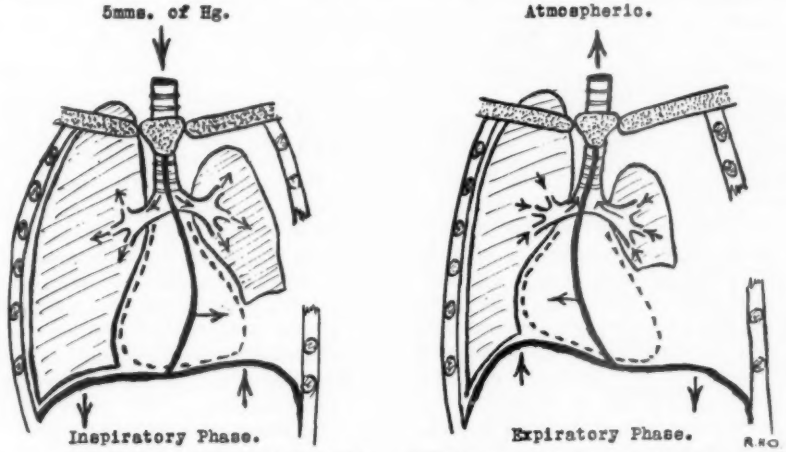


FIGURE III. Controlled respiration. Respiration no longer paradoxical.

thorax there is a rise of pulse pressure with the commencement of control and this is due to a disproportionate fall in the systolic and diastolic pressures.

With controlled respiration muscular effort is reduced to a minimum. The respiratory muscles are quiescent and the only major consumption of energy is by the cardiac system. Therefore the metabolism is reduced to the lowest possible value and prolonged operations do not exhaust the patient. With open thorax and spontaneous respiration there is a vicious circle which further increases the metabolic rate. The increased respiratory effort called forth by the open thorax raises the metabolism and this increases the carbon dioxide output, which in turn demands a still greater respiratory effort for its elimination. With controlled respiration this vicious circle is converted into a helpful one. The lowered muscular effort resulting from the apnœa decreases the metabolism and therefore the carbon dioxide output. This reduces the irritability of the respiratory centres in the brain and aids in maintaining the state of apnœa.

In regard to surgical access there can be little doubt that in the thorax this is better with the use of control. It is found that once a surgeon has become accustomed to working without spontaneous respiratory movement

of the patient, should the anæsthetist allow diaphragmatic contractions to return, then the surgeon immediately requests that control should be reestablished. In abdominal surgery the absence of voluntary respiration provides quieter conditions than are possible with other forms of anæsthesia. Such operations as involve the diaphragm are greatly simplified by the absence of its movement.

The blood changes that occur during anæsthesia have been discussed in a previous paper.[12] Briefly it may be stated that with such agents as cyclopropane there is a steady rise in the carbon dioxide level of the blood as the anæsthesia deepens and the patient is allowed to breathe spontaneously. This fact has an important bearing upon post-anæsthetic shock. It has been shown by Dripps[13] that the condition spoken of as "cyclopropane shock" is due to this rise in the carbon dioxide tension of the blood during anæsthesia. It seems probable that the condition of shock that sometimes follows the use of curare is due to the same cause. With controlled respiration the tidal respiration of the patient is maintained at its normal value in spite of the depression from the premedication, the anæsthetic agents or the curare. The tension of carbon dioxide in the blood is normal throughout the administration of the anæsthetic, and post-anæsthetic shock does not appear. In the past the importance of normal carbon dioxide blood levels during anæsthesia has received little attention; but now that it has been recognized the necessity for the use of controlled respiration in any form of anæsthesia that causes respiratory depression is obvious.

## MUSCULAR RELAXATION AND CURARE.

Drugs used for the production of general anæsthesia have three important actions which are common to all. Firstly, they render the patient unconscious and insensible to pain; secondly, they produce, to a varying degree, relaxation of voluntary muscles; and, thirdly, they cause progressive depression of respiration. Whilst the first property is desired by the patient and indeed is essential for a drug to be of use as a general anæsthetic agent, the second is of main interest to the surgeon. The third factor has in the past been a source of worry to the anæsthetist and of danger to the patient. Loss of consciousness is due to the depressant action of the drugs upon the cortical neurones and respiratory depression to the effects upon the medullary centres. Muscular relaxation cannot be explained on these grounds, as tone in the abdominal muscles is a spinal reflex, and any depression sufficient to abolish this would cause medullary paralysis.

The reason why muscular relaxation appears during general anæsthesia and varies with the agent employed has been elucidated by the discovery that anæsthetic drugs possess, to a varying degree, curare-like actions. Curare produces muscular relaxation by blocking the transmission of impulses across the myoneural junctions. Normally, these transfers take place by the liberation of acetylcholine on the arrival of each nervous impulse, the acetylcholine in turn stimulating contraction of the muscle fibres. Curare, by antagonizing the acetylcholine, prevents muscular contraction, even though there is no interference with the transmission of nervous impulses to the myoneural junction.

By using curare in anæsthesia no new principle is being employed. In the past the curare-like actions of anæsthetic drugs were obtained only by the use of deep anæsthesia. The objectionable features of deep anæsthesia were tolerated because it was not possible to produce adequate muscular relaxation without these unwanted effects. Today, instead of fortifying the curare-like action of anæsthetic agents by deepening the plane of anæsthesia,

it is possible to employ a light plane and to obtain the desired relaxation by the administration of curare. It must be borne in mind, however, that, no matter how abdominal relaxation is obtained, it must of necessity involve intercostal paralysis and therefore respiratory depression. Accordingly, when curare is used in abdominal surgery the anæsthetist should be in a position to assist, if not fully to control, the respiration.

## THE THEORY OF ACTION OF GENERAL ANÆSTHETIC AGENTS.

In advocacy of the use of curare repeated references have been made to the virtues of light anæsthesia. Crile[40] originally propounded the theory that under light anæsthesia stimuli continued to reach the brain and resulted in shock of neurogenic origin. This idea has proved to be entirely erroneous. It has been demonstrated that short periods of deep anæsthesia are far more productive of shock than prolonged periods of light anæsthesia. In order to understand this fact it is necessary to consider briefly the usually accepted theory of general anæsthesia, namely, that of oxygen deprivation.

According to the oxygen deprivation theory of general anæsthesia the effects of the agents are due to the suboxygenation of the cerebral tissues. The brain cells may be deprived of oxygen in one of three ways. Firstly, the oxygen content of the blood passing to the cells may be lowered; secondly, the intracellular enzymes may be rendered incapable of using oxygen; or, thirdly, some combination of these may be used. The first form of anæsthesia is never used; but it is classically demonstrated by the gradual replacement of the oxygen content of the air with nitrogen. When the oxygen content of the inhaled gases is lowered to about 6% unconsciousness results. This is brought about by a general anoxia of all tissues, including the brain, and this form of anoxia is spoken of as "anoxic anoxia", indicating that it is due to a reduction in the oxygen content of the inhaled gases. This anæsthesia is accompanied by cyanosis and, if any attempt is made to deepen it by further lowering of the oxygen content, asphyxia and convulsion result. The liver, heart and other organs are damaged by the general anoxia which is present, as there is no selective action on the cerebral tissues.

The second form of anæsthesia is exemplified by the actions of such drugs as ether and chloroform. These substances have the power of inhibiting the normal intracellular enzymes which are responsible for the utilization of oxygen by the tissues. The anoxia which results from the blocking of intracellular enzymal activity is spoken of as "histotoxic anoxia". Many substances, such as the cyanides, are available which produce histotoxic anoxia, but which are not used as general anæsthetic agents. Since brain tissues are rich in lipoids, and such drugs as ether and chloroform are lipoid solvents, a higher concentration is obtained in the nerve cells than in other cells of the body. Therefore these substances have a selective affinity for the cerebral tissues and are useful as general anæsthetic agents. In the lighter planes of anæsthesia with these drugs there is slight histotoxic anoxia of all tissues; but when the deeper planes are reached this becomes gross. The important fact to be remembered in regard to histotoxic anoxia is that it is not accompanied by cyanosis and is not overcome by increasing the oxygen content of the inhaled gases. This form of anoxia is particularly damaging to the liver and heart during prolonged deep anæsthesia.

The third way in which anæsthesia may be produced is by a combination of the previous effects. Such drugs as nitrous oxide and ethylene have only slight selective affinity for cerebral tissues, and it is necessary to lower the oxygen content of the gas mixture below that of the atmosphere to produce unconsciousness. With these drugs light anæsthesia is associated with slight

anoxic anoxia, which becomes severe if an attempt is made to reach a deep plane of narcosis. This form of anoxia usually is productive of cyanosis, which acts as a danger signal, but, if persisted with, will cause damage to all tissues.

It thus becomes apparent that, with light anæsthesia, however produced, there is only slight sub-oxygenation of the tissues. On the other hand, during deep anæsthesia there is always marked reduction in the oxygen available to the cells. With impotent agents, such as nitrous oxide, this in most instances is associated with cyanosis; but with powerful drugs, such as ether, cyclopropane and "Pentothal sodium", no such warning may be present. Even though the blood is perfectly oxygenated and red, the cells of the liver and heart may be unable to utilize the oxygen carried to them. Therefore it is in the best interests of the patient to employ on all occasions the lightest plane of anæsthesia that is compatible with the operation being performed. With the use of curare it is never necessary to do more than ensure unconsciousness and quiescence, the muscular relaxation being obtained when required without adding any toxicity to the administration.

## SURGERY OF THE ABDOMEN.

In abdominal surgery the condition that the surgeon desires before all others is adequate relaxation of the abdominal muscles. Without this many operations are traumatizing to the patient's tissues and to the surgeon's temper. The tone of the abdominal muscles is maintained by a spinal reflex, and it is necessary to break this at some point. Blocking of the intercostal nerves results in abdominal relaxation by interrupting the sensory side of the arc. Since the method is not employed widely in this country it is not proposed to discuss it in detail.

High spinal analgesia acts partly by blocking afferent impulses; but in addition it interrupts the efferent outflow, so breaking the reflex of muscular tone. Muscular relaxation in the abdomen, when produced in this manner, must be associated with paralysis of the intercostal muscles, as the nerve supply is the same in both cases. This paralysis produces respiratory depression, which results in a diminished tidal exchange of the respired gases, and two effects follow. Firstly, there is a lowered intake of oxygen and, secondly, a reduced output of carbon dioxide. The former may lead to anoxic anoxia, which will be evidenced as duskiness of the patient; but this is readily overcome by efficient administration of oxygen. The latter, however, produces carbon dioxide retention in the blood, and no form of therapy, short of artificial respiration, will overcome this defect. High spinal analgesia must result in disturbances of the acid-base balance in the blood so long as the respiratory depression persists.

Relaxation of the abdominal muscles may be produced by deep anæsthesia induced by a potent agent having a powerful curare-like action. As has already been shown, such anæsthesia causes marked histotoxic anoxia of all tissues and, since this is due to a direct poisoning of the cells, no therapy, short of lightening the anæsthesia, will benefit the patient. In addition, the curare-like action of the drug which produces the muscular relaxation will paralyse the intercostal muscles and bring about respiration depression. Once again anoxic anoxia and carbon dioxide retention will appear; but in this case they can be overcome with controlled respiration. Before the introduction of curare, with such a drug as cyclopropane, it was impossible at times to obtain deep anæsthesia because of the respiratory depression. By the use of control the patient could be carried through into the desired depth of anæsthesia. Today such methods cannot be recommended, as the

histotoxic anoxia of deep anæsthesia remains, no matter whether control is established or not.

Light anæsthesia with such agents as cyclopropane or "Pentothal sodium" is pleasant for the patient, has a low incidence of post-anæsthetic vomiting, and is not damaging to the tissues. It is not associated with histotoxic anoxia and produces minimal disturbance of the metabolism. When curare is used to obtain relaxation, no further toxicity is added to the administration; but the degree of curarization that will relax the abdominal muscles will also paralyse the intercostals. Once more the anæsthetist faces respiratory depression with the problems of anoxic anoxia and carbon dioxide retention. By the use of controlled respiration both these difficulties are surmounted, the tidal exchange is returned to normal, and the patient is restored to the satisfactory state of light anæsthesia.

It will be noted that cyclopropane and "Pentothal sodium" have been mentioned in this discussion, but not ether nor nitrous oxide. The use of curare in conjunction with ether anæsthesia does not appear to be justifiable. Ether itself has a strong curare-like action, and any administration of curare with it may lead to diaphragmatic paralysis. In the hands of a skilled anæsthetist this need cause no embarrassment, provided the ether is being administered through some apparatus that allows the use of controlled respiration. Since such equipment is obligatory when curare is given, it would seem preferable to employ some agent other than ether which has less unpleasant sequelæ for the patient. An incidence of some 40% in post-anæsthetic vomiting is unavoidable with ether, and this can be reduced to negligible amounts by the use of other agents. Nitrous oxide can be used as the anæsthetic agent; but larger doses of curare are required and the margin between loss of consciousness and anoxia is small. At the present state of our knowledge the most satisfactory agents to employ with curare are cyclopropane and intravenously administered barbiturates. Cyclopropane is administered through a gas machine with the use of carbon dioxide absorption, and the anæsthetist is always in the position where he can control the respiratory depression. The intravenously administered barbiturates normally do not require the presence in the operating theatre of a gas machine. Whenever curare is to be used it is essential that such a machine should be present so that oxygen can be administered and respiration assisted or controlled. Under such conditions curare is a safe drug, the toxic dose being some fifteen times that which will paralyse the diaphragm. Curare is not a remedy for poor anæsthesia. In the hands of the capable anæsthetist it adds no risk to the administration and reduces the post-anæsthetic morbidity; but, if used by one unskilled in modern techniques, it can endanger life or at least give no added benefit to the patient beyond those conferred by older methods.

## SURGERY OF THE THORAX.

Intrathoracic surgery has developed rapidly during the last ten years and many of the advances have been made possible by the introduction of improved anæsthetic methods. It is not suggested that no intrathoracic operation is possible without controlled respiration; but it is certain that the hazards of many are reduced greatly by its use. Spontaneous respiration, with an open thorax, is inefficient at the best, and when mediastinal "flap" or paradoxical respiration is severe may lead to gross disturbance in the physiology of the patient. Controlled respiration avoids the embarrassments and allows prolonged surgery without the production of shock.

Curare was first used in thoracic surgery by Harroun and Hathaway.[8] The surgeons with whom they worked desired to employ the endotherm and,

with this in view, they anæsthetized their patients with nitrous oxide. Apart from chloroform and trichlorethylene, neither of which is suitable for chest surgery, this is the only non-inflammable inhalational agent available, and it must be remembered that the addition of ether to this gas renders it not inflammable but explosive. With nitrous oxide unaided by volatile supplement intrathoracic surgery is impossible, so that Harroun and Hathaway administered large doses of curare at frequent intervals. The doses that they employed produced and maintained complete respiratory paralysis throughout the operation. Such a degree of curarization, which causes general muscular flaccidity, now is considered unsound, as reduction of the circulating blood volume ensues from pooling in the muscles and shock is produced.[15][16] The surgeons were paying too high a price for the use of the endotherm, and if its employment is imperative it is preferable to administer an intravenous barbiturate together with curare, as has been suggested by Halton.[9]

A problem which confronts the anæsthetist during operations upon the lungs is the presence of active bronchial reflexes which are stimulated by secretions or by surgical handling. In the past the anæsthetist has attempted to control these by deepening the plane of anæsthesia. With ether this is accomplished at the cost of delayed recovery, and with cyclopropane cardiac irregularities are apt to appear before the reflexes are abolished. The literature on curare is confused in regard to its actions upon the nervous system, but there is some evidence[17][18][19][20][21][22][23] that it influences the transmission of impulses via the vagi. Following the clinical use of curare for laryngeal intubation, when it was noted that the bronchial reflexes were abolished, it was decided to administer the drug during thoracic operations in conjunction with cyclopropane. It was found that, with doses which did no more than abolish intercostal activity, bronchial reflexes were absent and light planes of anæsthesia could be entered without disturbance of the patient. With this degree of curarization voluntary movement of the limbs was frequently observed; but there was no reflex response to stimulation of the bronchi by the surgeon or the anæsthetist. Some fifty major thoracic operations now have been performed with the use of this technique with gratifying results. Consciousness and active reflexes return within one minute, even after prolonged surgery; no post-operative shock has been encountered and in only one case has the patient vomited at all. From clinical evidence it would appear that curare is capable of controlling bronchial reflexes and in relatively small doses. If this action is due to vagal block, as was suggested by Claude Bernard,[19] then the dangers of vagal inhibition of the heart during light anæsthesia are abolished. That such block of vagal impulses to the heart does occur is suggested by the tachycardia that appears when curare is administered to the conscious patient;[24] but the complicated nature of the process is indicated by the fact that, in the anæsthetized patient, such acceleration of the pulse occurs only when the anæsthesia becomes unduly light. In thoracic surgery, therefore, efficient respiratory exchange is possible under light anæsthesia and with abolished bronchial reflexes by the combined use of controlled respiration and curare.

## CONCLUSION.

Contrary to previously held ideas, light anæsthesia does not produce shock, but helps to avoid it. In the past it has been necessary to use deep anæsthesia for abdominal and thoracic surgery in order to obtain muscular relaxation and abolition of reflexes. Today this is no longer needed, as with curare both these conditions are realized with light anæsthesia. The respiratory depression that results from the use of this drug can be countered with assisted or controlled respiration.

But the safe use of curare and of controlled respiration demands a high degree of skill on the part of the anæsthetist. If surgeons desire this skill, then they must give to their anæsthetists adequate recognition for their part in a surgical procedure and realize that the anæsthetist is a vital part of any surgical team.

## SUMMARY.

1. Controlled respiration possesses advantages over voluntary respiration in thoracic surgery and should be employed during abdominal surgery whenever respiratory depression occurs. By its use normal exchange of oxygen and carbon dioxide is possible in all circumstances.

2. By producing muscular relaxation and abolishing reflexes curare allows the use of light anæsthesia and therefore aids in the avoidance of shock.

3. In abdominal surgery, light anæsthesia, combined with the use of curare and controlled respiration, produces the minimum disturbance in the patient compatible with adequate muscular relaxation.

4. In thoracic surgery curare controls bronchial reflexes and with controlled respiration gives the most satisfactory conditions for surgery.

5. The use of controlled respiration and of curare demands a high degree of anæsthetic skill.

## ACKNOWLEDGEMENTS.

I should like to take this opportunity of thanking some of the surgeons who have encouraged me in my work—firstly, of course, Mr. C. J. Officer Brown, with whom I have worked for some eight years at the Alfred Hospital and with whom I am happy to be associated in our thoracic surgical unit. At all times he has shown intense interest in my endeavours and at no time has he complained when I have inflicted new methods upon him. Together we have tried most forms of anæsthesia available for thoracic surgery and without his support the material for this paper would not have been available.

Secondly, I should wish to thank Mr. Henry Searby, who has stepped out of thoracic surgery to make a place for a specialist in that branch. His encouragement has done much to help me reach the position that I now hold, and it was with much regret that I was forced by pressure of work to forgo the pleasure of administering anæsthetics for him at the Royal Melbourne Hospital.

Others that I should mention are Mr. Upjohn, who insisted upon the value of carbon dioxide absorption methods of anæsthesia; Mr. Leo Doyle and Mr. F. J. Colahan, both of whom appreciated the merits of controlled respiration. I trust that my other surgical colleagues, too numerous to mention, will all accept my thanks.

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# STRESS INCONTINENCE IN THE FEMALE.[1]

By P. A. Treahy and H. K. Pacey,
*Wellington, New Zealand.*

It has been apparent for some years that the treatment of stress incontinence in the female has not been entirely satisfactory. A urologist naturally sees those cases in which operative treatment, sometimes oft repeated, has failed to cure the condition. In none of these cases has it ever been possible to demonstrate any intrinsic lesion of the bladder. The cystoscopic appearance of the bladder neck does not in any way depart from the normal. There is never any evidence of true incontinence. However, the most important finding common to all these cases is the persistent descent of the front wall of the vagina with the urethra and bladder base.

The operative procedures have been performed by competent surgeons, who would naturally be conversant with the standard operation and with any recent improvements or modifications, yet these failures have been occurring too frequently. It seemed then that the standard operation was perhaps faulty in its conception. The aim of the operation for descent of the front wall and cervix is to replace the cervix, bladder and urethra into the pelvic cavity and to hold them there by an operative technique which makes use of the pubo-cervical fascia to form the main support. Differences in technique are really only differences in the method of suture. It would seem that an investigation into this problem might be profitable.

In considering the theoretical probabilities, an appeal to physiology leaves one with the firm conviction that the condition is not in any way related to sphincter damage, and therefore that any further investigation along these lines would be unproductive.

A careful study of the actual mechanism of the incontinence as it occurs shows quite clearly and beyond doubt that the urine is not passed. It escapes in a spurt from the urethra only during the period of time in which the expulsive force, in this instance a cough, is actually in force. It ceases with the relaxation of the stress and there is no dribbling. Moreover, the amount of urine that escapes is in direct relationship to the amount of force expended—that is, the harder the cough, the greater is the amount ejected. It is important to realize this distinction, as it at once suggests that the sphincter mechanism is not at fault. It also leads one to the supposition that the cause might lie in the inability of the supporting mechanism of the bladder to cope with this sudden increase of intraabdominal pressure.

In the normal woman there is an intact pelvic floor. The pelvic floor aperture through which the excretory channels communicate with the exterior is also intact. The bladder is supported by the pelvic floor, so that any sudden increase of intraabdominal pressure will be taken by this structure and thereby dissipated, so that there will be no sudden rise of intravesical pressure.

It has already been stated that the common finding in all these cases is the descent of the front wall; therefore one is forced to the conclusion that there is a herniation through the pelvic floor aperture. This is, of course, in keeping with the modern trend of thought on this condition. Herniation of

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the bladder base and urethra through the pelvic floor aperture must alter the mechanics of this region considerably, so that when any sudden increase of intraabdominal pressure occurs it will not be dissipated over the pelvic floor, but will be concentrated in the smaller compass of the hernia, exactly as it is in the inguinal hernia. This must then lead to a considerable increase of pressure in the contents of the hernia, one of which is a pouch of the bladder in which is situated the orifice of this organ. It is, then, not so difficult to see how this rise of pressure may be sufficient to force the sphincter and so lead to the expulsion of a small quantity of urine. This may, of course, occur without any detrusor contraction; in fact there is no time for such a contraction to occur. The bladder musculature adopts a purely passive role during the period of the stress.

A consideration of the anatomy of the pelvic floor may help to throw some more light upon this problem.

The pelvic floor consists of layers of skeletal striated muscle and fascia. Its most important part is the upper muscular layer, often termed the pelvic diaphragm (by comparison with the diaphragm which limits the abdomino-pelvic cavity above), and composed of the *levator ani* and coccygeus muscles. The *levatores ani* muscles of the two sides form the principal support for the pelvic viscera, namely, the bladder in front, the rectum behind, and the uterus and appendages interposed between. These organs have their outlets through the pelvic diaphragm, by means of the pelvic floor aperture, and it is obvious that, in the living body, the one type of tissue particularly specialized to serve as an adjustable support (in the presence of variations in intra-abdominal pressure), and at the same time to permit the passage of structures through it, is voluntary striated muscle. This is well seen in the inguinal region, where, in the male, the lower fibres of the internal oblique and transversus muscles arch over the spermatic cord, forming what has been termed the "inguinal shutter". While the pelvic diaphragm must present one or more gaps through which pass the urethra, the vagina and the anal canal, and while these points of egress are naturally the weakest parts of the diaphragm, it is clear that normally the muscular fibres are so arranged as to supply efficient support. The *levatores ani* of the two sides form a muscular sling behind the anal canal and a further muscular sling behind the vagina, between it and the anal canal; it is not improbable that there is a similar, though less obvious, prolongation of muscular fibres between the urethra and the vagina. Further, the fascia related to the muscles merges into the fibrous coverings of the organs that pass through, so tending to weld these parts into a firm barrier against descent. In fact, these structures have been described as an obturator which fills the pelvic floor aperture. The *levator ani* muscle consists of two parts, the ilio-coccygeus and the pubo-coccygeus; it is with the latter that we are more particularly concerned. The pubo-coccygeus, which is thicker than the ilio-coccygeus, takes origin from the dorsal or pelvic surface of the *os pubis*. Its fibres pass almost horizontally backwards, lateral to the urethra, the vagina and the anal canal. While some are inserted into the coccyx, the remainder become continuous with their fellows of the opposite side, forming the muscular slings, referred to above, behind the anal canal, behind the vagina, and probably to a less extent behind the urethra.

In the repair of this hernia it is advised that instead of depending on closing the defect by the use of the pubo-cervical fascia, as is the case in the standard operation, the surgeon should use instead the pubo-coccygeus muscle itself. This muscle is readily accessible in the area of operation and should be united in the mid-line below the urethra and bladder base from a

point as near the external urinary meatus as possible to a point in front of the cervix.

## DIAGNOSIS.

It is important that the diagnosis should be accurate. Any disease of the bladder must be excluded. A distinction must be made between urgency and precipitancy and stress incontinence, otherwise the operation will be performed for inflammatory conditions. The examination of the patient should be carried out under vision and the patient must be expected to demonstrate the condition to the full satisfaction of the examiner. He should first examine the bladder with the cystoscope and, having satisfied himself that there is no intrinsic lesion of that organ, then fill the bladder with water until the patient agrees that she feels comfortably full and would not like to hold any more. The cystoscope is then withdrawn and the external meatus is inspected to ascertain that there is no leakage or true incontinence. The patient is then asked to cough and in the severe case a good jet of water will spurt from the meatus. This will cease immediately and there will be no dribbling. Two fingers of the left hand reversed are then placed in the vagina on either side of the urethra and the base of the bladder is supported while another cough is performed. It will be noted now that no water escapes, although there is no pressure on the urethra.

The patient, who has till now been in the lithotomy position, is asked to stand upon the floor, a kidney dish is placed between the thighs and another cough demanded. The result of this is then inspected; it will generally be found that a much more decided spurt escapes in this position and in some cases when there has been practically none when the patient is in the recumbent position, there will be a considerable amount when she is in the erect position. The patient is also asked to pass urine and to stop the act of micturition voluntarily. It will be seen that the sphincteric mechanism is acting perfectly. The patient will demonstrate that she can pass urine at will, stop it at will and is not truly incontinent.

## OPERATION.

Mr. H. K. Pacey, a gynæcologist, who has been associated with me in this research, and who has perfected the operative technique necessary for the incorporation of the principles expounded in the preceding text, will give his description of the procedure.

Access to the subvesical area is obtained by opening the front wall of the vagina by whatever technique the surgeon cares to use. The vaginal incision must be carried right to the external urinary meatus. Flaps of vaginal mucosa and of pubo-cervical fascia are turned outwards. The bladder must now be mobilized freely from the uterus and from the pubo-cervical fascia laterally. This must be sufficiently free for the bladder to be displaced readily from view into the pelvis.

The plane of cleavage between the bladder and fascia must now be extended forwards so as to detach the urethra on each side from fascia and from abnormal adhesions to the ischio-pubic ramus. The urethra must be dissected forwards as far as the external meatus and the dissection at each side deepened so that the seeking finger readily impinges on the back of the *os pubis* in front and on the inner aspect of the ischio-pubic ramus laterally.

If, now, the flaps of mucosa and fascia are taken up together in a generous bite by Allis forceps and are pulled outwards, and if the urethra is retracted in the opposite direction, the depths of the para-urethral fossa can be inspected readily. Deep in the fossa, on the lateral wall, there will be seen a pearly white band of tissue, running antero-posteriorly. This can

readily be picked up and demonstrated by another Allis forceps (Figure I). This is the edge of the pubo-coccygeus muscle with its fascia. It must be stitched to its fellow of the opposite side with interrupted sutures of light chromicized catgut. The union must be carried forwards until the foremost suture is commencing to compress the urethra, and backwards until the gap through which the bladder herniates has been obliterated.

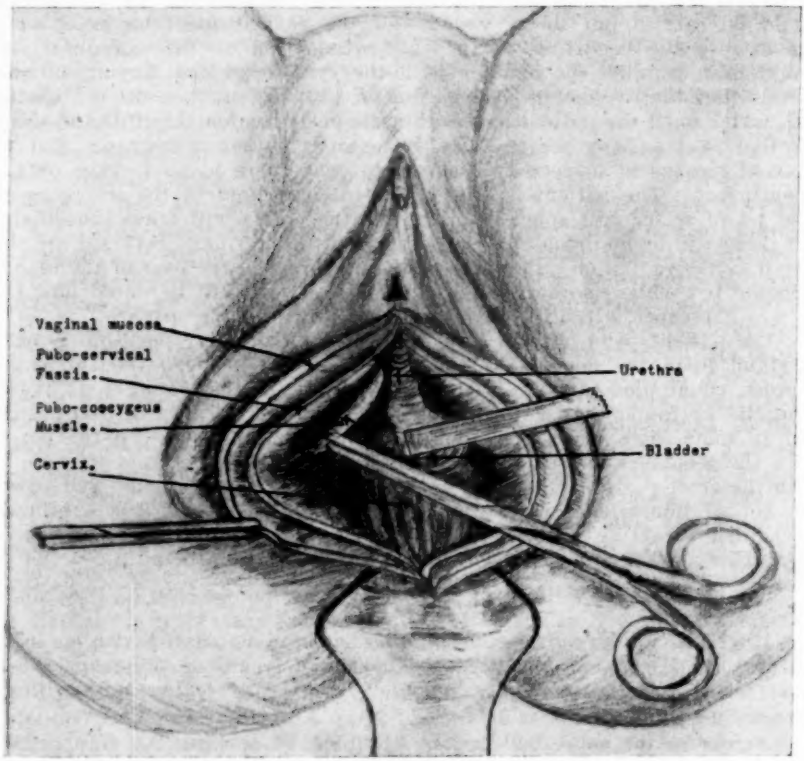


FIGURE I.

The operation is completed by suture of the pubo-cervical fascia and vaginal wall, combined with such steps for the repair of prolapse as may be necessary. A small self-retaining catheter is introduced into the bladder. Continuous drainage of the bladder is maintained for a period of about ten days, after which time the catheter is removed. At this stage the patient may not be able to pass urine naturally and the catheter may have to be replaced for a further period. The use of chemotherapeutic agents is necessary to help in combating urinary infection from the use of the catheter.

## CASE HISTORIES.

The following is a summary of a series of thirteen consecutive cases. The major complaint in all cases was stress incontinence, and the operation of suture of the pubo-coccygeus muscle was performed in all of them. Suture of the pubo-coccygeus muscle has since been incorporated in the technique as

a routine step in the operation for prolapse; however, no such cases have been included in this series.

CASE I.—The first patient, who was operated on on May 6, 1945, was Mrs. W.O.M.L., forty-six years of age. She had two children and had had a cystocele and stress incontinence since the birth of her first child fourteen years previously. The cystocele was repaired eight years previously, with no relief of the incontinence and with subsequent recurrence of the cystocele. She was the first patient on whom an attempt was made to apply the new principles. On this occasion we were not successful in demonstrating the muscle to our satisfaction and the operation was a failure. On November 29, 1946, she submitted to a further operation, and this time the muscles were demonstrated clearly and were well sutured. The cardinal ligaments were advanced and the cervix was amputated. On May 5, 1947, her doctor reported perfect control of the bladder.

CASE II.—Mrs. D.M. was fifty years of age. She had a first degree vault prolapse, a large cystocele and severe stress incontinence. On September 29, 1945, she had a suture of the pubo-coccygeus muscle, combined with a repair of the prolapse with amputation of the cervix and posterior colpo-perineorrhaphy. On December 28, 1945, she reported that she was delighted with the result.

CASE III.—Mrs. E.H. was sixty-three years of age. On July 2, 1943, I repaired her prolapse, amputating the cervix and doing posterior colpo-perineorrhaphy. She had made no complaint of stress incontinence at the time. Three years later she reported with a gross degree of this condition. Examination showed an excellent prolapse result. At the second operation, performed on June 28, 1946, suture of the pubo-coccygeus was the only procedure. On June 29 she wrote describing the result as "successful beyond my hopes".

CASE IV.—Mrs. R.M. was forty-two years of age. On July 13, 1946, she submitted to suture of the pubo-coccygeus, repair of prolapse and posterior colpo-perineorrhaphy. On October 21, 1946, she reported an excellent result.

CASE V.—Mrs. G.G. was forty-eight years of age. She complained of menorrhagia, complete prolapse and stress incontinence. On September 3, 1946, she underwent the Mayo operation of vaginal hysterectomy for prolapse. The pubo-coccygeus muscles were sutured at the same time. The result was excellent for the prolapse and there is complete control of the bladder.

CASE VI.—Mrs. I.D.B. was twenty-nine years of age. She had three children. She had had to abandon tennis, golf and riding because of stress incontinence. On September 10, 1946, she underwent suture of the muscles. She has since resumed her sporting activities with full control of the bladder.

CASE VII.—Mrs. A.S.D. was fifty-one years of age. She had three children. She complained of irregular bleeding and stress incontinence. The bleeding was from a cervical polypus. The only deformity of the vagina was a moderate prolapse of the front wall, the so-called urethrocele. On September 30, 1946, the polypus was removed and the pubo-coccygeus muscles were sutured. She later reported perfect control of the bladder.

CASE VIII.—Mrs. J.H. was thirty-nine years of age. She had two children. She had procidentia and severe stress incontinence. On October 29, 1946, she had suture of the pubo-coccygeus muscles, repair of prolapse and posterior colpo-perineorrhaphy. The result was complete cure.

CASE IX.—Mrs. A.B.C. was thirty-six years of age. She had three children, all born by the breech with extended legs. She had a moderate prolapse and stress incontinence. On January 17, 1947, she had a suture of her pubo-coccygeus muscles and a repair of the prolapse. Three months later she expressed complete satisfaction.

CASE X.—Mrs. M.R.G., was thirty-three years of age. She had two children. On February 20, 1947, she underwent repair of prolapse with suture of the muscles. At three months from operation she was completely satisfied.

CASE XI.—Mrs. A.L.S. was fifty-four years of age. She was the wife of a provincial surgeon and had three children. She had undergone three operations for prolapse, two in New Zealand and one in London. She still complained of prolapse and stress incontinence. On May 14, 1946, she underwent a further repair of the prolapse, suture of the pubo-coccygeus muscles and posterior colpo-perineorrhaphy. On February 26, 1947, when visited in her home town, she proclaimed the operation a complete success.

CASE XII.—Mrs. D.L. was forty-two years of age. She had one child. Her only complaint was stress incontinence. On February 24, 1947, she had her pubo-coccygeus muscles sutured. On April 29 she stated that she was well pleased with the result.

CASE XIII.—Mrs. A.P. was the wife of a surgeon. She had two children and had undergone total hysterectomy on May 22, 1944, for menorrhagia. She developed a disabling stress incontinence about one year ago. She had no prolapse of the vaginal walls. On April 10, 1947, her pubo-coccygeus muscles were sutured. At the time of writing, one month later, it is early to report results, but she has communicated her great delight with the condition so far.

These cases comprise a series of thirteen consecutive cases in which the major complaint was stress incontinence. There have been no omissions from the series. It must be noted that every one of these women expressed complete satisfaction with the results of the operation. In fact, it seems that it may be claimed that this procedure yields 100% perfect results.

## SUMMARY.

1. An explanation of stress incontinence in the female has been attempted.

2. An operation for the cure of this condition is described.

3. A series of cases is included.

## ACKNOWLEDGEMENT.

We are indebted to Mr. John Cairney for his help and advice on the anatomy of the pelvic floor.

# OBSERVATIONS ON INJURIES OF THE RADIAL NERVE DUE TO GUNSHOT WOUNDS AND OTHER CAUSES.[1]

By SYDNEY SUNDERLAND,
*Department of Anatomy and Histology, University of Melbourne.*

THIS paper, the third of a series devoted to the results of an investigation of 301 cases of peripheral nerve injury due to gunshot wounds and other causes, is concerned with lesions of the radial nerve and is based on the personal records of 63 cases treated in the 115th Australian General Hospital over the period 1941-1945. A follow-up of those patients discharged from the services has been made possible through the courtesy and kind offices of the Victorian Repatriation Department. In this way it has been possible to maintain an unbroken record of the sequence of events following injury to nerves which has, in some cases, extended over four years.

During an investigation extending over several years and involving patients who are occasionally inaccessible for examination at the required intervals, gaps in the records are inevitable. Particularly is this so when the series is large, time is limited and the investigation is the concern of a single observer. Occasionally it was not possible to establish the onset of recovery in a muscle accurately to within one week since patients were not always available for examination at critical periods during regeneration. In these cases the times noted were the last date when the muscle was known to be paralysed and the date when contraction was first observed. Similarly it was often impracticable to estimate wasting metrically at every examination and therefore some records are deficient in data bearing on the relation of wasting to the loss and recovery of function. It is believed, however, that omissions of this character are compensated for by the fact that every examination has been made by the same observer.

## TYPES OF INJURY RESPONSIBLE FOR THE NERVE LESIONS.

For purposes of comparison the nerve injuries have been classified, on the basis of the agency responsible for the injury, into the following groups:

I. Simple compression lesions. This group has been covered in a previous paper (Sunderland, 1945). Three additional cases confirm, but add nothing new to the conclusions there reported. The only reference to this group in the present report is the inclusion of the 10 cases in the discussion of the end results and in Tables II, IX and X to show their numerical relationship to the other groups.

II. Lesions associated with lacerations and penetrating injuries other than gunshot wounds.

III. Lesions associated with simple fractures of the humerus.

IV. Lesions due to gunshot wounds not causing injury to bone.

V. Lesions due to gunshot wounds with a concomitant injury to bone.

## SITE OF INVOLVEMENT.

The upper arm has been divided into three sections for the purpose of defining the site and level of the lesion. In the upper third of its course the

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nerve traverses the axilla and the brachio-axillary angle, which is defined as the angle between the lower border of the posterior axillary wall and the point where the nerve passes between the two heads of triceps. In the mid-third of the arm the nerve is related to the bony spiral groove, while in the lower third it occupies the intermuscular furrow between the brachialis medially and the brachioradialis and *extensor carpi radialis longus* laterally. The terms "spiral groove" and "intermuscular furrow" have been abbreviated to "groove" and "furrow" respectively throughout the text.

### NATURE OF THE NERVE LESION.

The lesions have been classed as complete or partial. These terms denote complete and partial interruption of conduction as ascertained by clinical examination supplemented where possible by direct examination of the nerve either in the wound or later at exploration. All but four of the lesions were complete. This may be explained by the fact that partial or transient lesions recovered before the patient reached the base hospital where these investigations were made.

### COMBINED LESIONS.

The present report is confined to a study of radial nerve lesions. When an injury of this nerve was combined with an injury to others, the radial alone has been discussed—the others will be covered in subsequent papers.

### ELECTRICAL REACTIONS.

Electrical reactions were taken as a routine in most cases. In general they proved unreliable guides to injury and recovery in damaged nerves and for this reason have not been included.

### WASTING.

Wasting was estimated by comparing the measurements of the circumference of both limbs 7·5 centimetres above and below the medial humeral epicondyle. In the case of extensive soft tissue injuries of the supracondylar region the measurements could not be taken.

### MUSCLE TERMINOLOGY.

The following abbreviated terminology has been used in the text and accompanying tables: brachioradialis, B.R.; *extensores carpi radiales,* E.C.R.; *extensor carpi ulnaris,* E.C.U.; *extensor digitorum communis,* E.D.C.; *abductor pollicis longus,* A.P.L.; *extensor pollicis longus,* E.P.L.

### INFECTION AND SCARRING.

An attempt has been made in each case to assess the degree of infection and local scarring about the nerve in order to evaluate the influence of these factors on the course of regeneration. This is difficult and only the simplest classification into "significant" and "insignificant" has been attempted.

The degree of infection has been assessed on the general symptoms, the culture obtained from the wound, the presence or absence of osteomyelitis, the period during which the wound discharged, the time taken for the wound to heal, and the extent of residual scarring.

The degree of scarring has been estimated on the extent of soft tissue injury, the area and character of the residual scar and whether this was adherent, free, depressed or otherwise.

## COURSE OF REGENERATION.

*Motor.*—In studying motor recovery particular attention was directed to the onset of contraction in the brachioradialis, *extensor carpi radialis longus, extensor digitorum communis, extensor carpi ulnaris, abductor pollicis longus* and *extensor pollicis longus.* When examining muscle function, no attempt was made to differentiate the *extensores carpi radiales,* or the *abductor pollicis longus* from the *extensor pollicis brevis,* or the segment of the *extensor digitorum communis* to the index finger from the *extensor indicis proprius.* In each case the two muscles have substantially the same actions and are so closely associated anatomically that it is often impossible to decide with absolute certainty by palpation when one is contracting and the other is not.

A study of the metrical and non-metrical features of the motor branches of the radial nerve in 20 specimens (Sunderland, 1946) has revealed that the shortest distance to the *extensor carpi radialis longus,* as measured from a fixed point along the nerve and its branches, was invariably shorter than that to the *extensor carpi radialis brevis.* The first contractions in this combined mass could therefore be attributed to the former providing the regenerating axones to each grow at the same rate and commence to do so at the same time.

In no instance were the shortest fibres to the *extensor indicis proprius* shorter than those to the *extensor digitorum communis.* In four specimens the *extensor digiti quinti* preceded the latter in the order of innervation, though in only two of these was the difference between their lengths significant. Consquently the *extensor digitorum* may, as a rule, be expected to recover before the other two and its action should not be attributed to them.

In every specimen the distance to the *abductor pollicis longus* was shorter than that to the *extensor pollicis brevis,* and therefore the first signs of returning function should, in uncomplicated recoveries, be attributed to the former.

Palpable contraction of the muscle, or movement which was undoubtedly attributable to its action alone, was the criterion adopted for detecting returning function. Due regard was paid to the possibility of transmitted contraction and trick movements (Sunderland, 1944).

In order to detect the earliest signs of recovery, patients were examined at weekly intervals until all muscles were contracting; from then onwards the examinations were conducted at monthly, then at three-monthly and finally at six-monthly intervals. Where weekly examinations were not possible and the first appearance of recovery could not therefore be given accurately to a specific week, the last date when the muscle was known to be still paralysed and the date when recovery was first detected have been given.

*Sensation.*—The term sensation in the text refers only to the response to pin-prick and to light touch elicited by the application of a camel hair.

## TREATMENT.

The treatment here described as "conservative" implies the use of non-operative measures (such as daily massage, heat, remedial and reeducational exercises and, in the late stages, occupational therapy) which were followed by either complete restoration of function or by recovery which was sufficiently advanced to contraindicate exploration of the nerve. Electrotherapy was not practised as a routine. There appeared to be no significant difference in the course of regeneration or time taken to establish complete restoration of function between those patients receiving and those who did not receive

electrical treatment; but this question was not fully investigated. There is, however, experimental evidence to indicate that electrical stimulation accelerates recovery (Gutmann and Guttmann, 1944, Jackson and Seddon, 1945).

Splints were applied in all cases in the form of light plaster moulds with mild hyperextension of the wrist, extension and partial radial abduction of the thumb and extension of the fingers at the metacarpo-phalangeal joints. I believe in the value of such support for the thenar and metacarpo-phalangal joints, provided that supervised movements are carried out daily. In no case did joint stiffness develop when these precautions were taken, but only followed prolonged, unrestricted and uncontrolled immobilization.

When the power of wrist extension had reached useful proportions and voluntary contraction had appeared in the digital and thenar muscles, the mould was discarded and a wrist band substituted which maintained extension of the metacarpo-phalangeal joints by means of rubber strips passing to digital and thenar cuffs. This permitted free and useful digital movements, while ensuring relaxation of the involved muscles during rest. The digits were supported thus until the power of extension of the fingers and of thenar radial abduction was strong enough to warrant their release.

Evidence has been obtained from this study that rest of paralysed muscles hastens and stretch delays recovery. In one group of patients the mould was discarded in favour of the rubber spring appliance before contraction had appeared in the *extensor digitorum communis* and the thenar muscles. Recovery of these muscles in this group was delayed in comparison with that in the group receiving support. Shortly after the hand was returned to the mould the *extensor digitorum* and thumb muscles rapidly recovered. For this reason the appliance was employed only when contraction had appeared in the digital and thenar muscles. Admittedly other factors could be responsible for the delayed recovery, but in these two groups the lesions were at the same level and the nature and condition of the wound suggested a similar type of injury.

Paralysed muscles are also easily overstretched and permanently lengthened, which reduces their efficiency when voluntary contraction returns. In some regions such overstretching is prevented by other muscles, which by their action provide periods of rest for the denervated muscle. Thus in ulnar nerve lesions the involved *flexor carpi ulnaris* is protected against overstretching by two agencies—flexion of the wrist by gravity and the action of the *flexor carpi radialis*. No such resting mechanism is available in the case of paralysis of the muscles supplied by the radial nerve, and failure to provide this in the form of suitable splinting will lead to their overstretching by gravity and by the action of unopposed antagonists.

## NEUROLYSIS.

When exploration revealed a nerve in continuity, treatment was confined to freeing the nerve from any surrounding scar tissue. The value of neurolysis is controversial—in only one case (No. 65) were conditions such that the subsequent recovery could be attributed, partly or wholly, to this procedure.

## SIGNS PRESAGING THE ONSET OF RECOVERY.

The development of tenderness in the involved muscles, elicited by pressure, was usually the first sign presaging the onset of recovery. This was followed by voluntary contraction, which was insufficient in the initial stages

to produce movement when the influence of gravity was eliminated. In some patients the appearance of swelling and tenderness of the synovial sheaths of the digital and thenar tendons was observed to foreshadow the onset of voluntary contraction in the corresponding muscles. The presence of an advancing Tinel's sign is an indication that regenerating axones are descending along the distal segment of the nerve, but not necessarily along sensory paths, so that this is not a guide to the ultimate functional result.

### EVALUATION OF THE END RESULT IN LESIONS OF THE RADIAL NERVE.

The end result has been evaluated in each case on the usefulness of the hand to the individual.

As a rule sensory defects in the field of the radial nerve do not impair function, and for this reason the end result in radial nerve lesions has been based solely on the state of motor function. In many cases there was an associated extraneural disturbance due to the temporary loss of nerve function, incorrect treatment and/or direct injury to extraneural tissues. The residual extraneural defect may adversely influence the function of the limb, but only the residual disability resulting from the nerve lesion itself has been considered in evaluating the end result. Throughout this study attempts have been made to separate the motor disability consequent on the nerve lesion from that due to causes not directly attributable to the interruption of conduction in the nerve. In combined lesions the end result has been expressed solely in terms of radial nerve function. Any residual defect attributable to injury to the other nerve or nerves will be contained in the report on those nerves. Finally, the controlling influence which the cerebral cortex exerts on the peripheral motor field is of considerable importance in the restoration of function.

The following are the categories of functional recovery which have been employed.

1. *Complete Restoration of Function.*—The function of the limb was normal in every respect when compared with the sound limb. This would represent Stage 5 in the Medical Research Council Memorandum (1942).

2. *Good.*—Some residual paresis and/or extraneural defect attributable to the nerve lesion, though this is not sufficient to impair the efficiency of the limb to prolonged effort or to influence adversely the patient's choice or execution of a trade or profession.

3. *Satisfactory.*—Recovery was complete only in the sense that all muscles were contracting to produce a range of movement against resistance. The range and power of the movements (principally those of the thumb and fingers) were, however, sufficiently impaired to limit the usefulness of the hand for certain manual tasks, so that the choice of a trade or profession was restricted, but routine daily acts, such as shaving, dressing and using a knife and fork, were not seriously affected. This condition probably represents Stage 4 in the Medical Research Council Memorandum.

4. *Fair.*—The range and power of all movements, or those of the thumb and finger only, were sufficiently impaired to limit the use of the hand in performing the simplest acts. The functional result, however, was assessed as better than that which could be obtained by resorting to tendon transplantation. Probably represents Stage 3 in the Medical Research Council Memorandum.

5. *Poor.*—Recovery registered in one or more muscles, but was of no functional value. Tendon transplantations were required to aid function.

This corresponds to Stages 1 and 2 in the Medical Research Council Memorandum.

6. *No Recovery.*—No regeneration. This corresponds to Stage 0 in the Medical Research Council Memorandum.

## CASE REPORTS.

Unless otherwise stated, the number of weeks given in the text represents in each case the period of time as calculated from the date of injury. This will avoid repetition of the phrase "after the injury". Details relating to the motor recovery and wasting are provided in Table VI and Table VIII respectively.

### *Lesions of the Radial Nerve Associated with Closed Fractures of the Humerus.*

**The nerve lesion dated in every case from the time of the injury.**

CASE 65.—B.E.M. was injured in a car accident on August 1, 1942, in which he sustained a comminuted fracture of the upper third of the shaft of the right humerus. There was a complete lesion of the radial nerve below the supply to the triceps, and the posterior cutaneous nerve of the forearm was involved. An examination of the skiagrams suggested that the nerve had been transfixed at the fracture site by a sharp upwardly directed spur of the distal segment; this was confirmed at operation. Continuous burning pain was felt in the superficial radial field for eight weeks.

The nerve was explored from the axilla to the spiral groove at twenty-four weeks. It was firmly adherent to the humerus at the fracture site and was freed with difficulty. Two small neuromata, separated by an inch of thinned nerve, were situated just above the site of adherence to bone. Stimulation proximal and distal to the injured segment did not produce any motor response. Excision of the involved segment was demanded, but this would have necessitated the insertion of a graft and, in the anticipation that the neurolysis might encourage regeneration, attempts at repair were abandoned.

**These findings demonstrate that the nerve can be severely lacerated in simple fractures of the humerus.**

There was no recovery thirteen weeks after the operation. When next examined, twenty-seven weeks later, all muscles supplied by the radial nerve were contracting to give a full range of movement against resistance (except for slight impairment of radial abduction of the hand and thumb). The power of the muscles progressively improved. When the patient was last examined at 191 weeks, all movements, with the exception of radial deviation at the wrist and radial abduction of the thumb, which were slightly limited in range and power, were fully and strongly executed. Synergic extension of the wrist was still defective—the power of the grip was one-half that of the opposite side. The impairment of radial deviation of the wrist was due solely to the residual paresis of the *abductor pollicis longus* and *extensor pollicis brevis*. The extent and depth of the cutaneous sensory disturbance were slightly reduced in the initial stages and then remained unchanged. The extraneural disability consisted of slight and temporary impairment of forearm extension and supination. The end result was satisfactory.

CASE 77.—A.F. sustained a fracture through the lower portion of the mid-third of the left humerous on August 3, 1942, when he was struck on the outer aspect of the left arm by a bale (six hundredweight in weight) which had fallen approximately 20 feet. The nerve lesion was complete above the branches to the brachioradialis, and the posterior cutaneous nerve of the forearm was involved.

Recovery appeared in the brachioradialis at 16 weeks, and by 27 weeks all muscles were contracting. At 50 weeks the patient was returned to service duties with motor function fully restored. Cutaneous sensation, though it had improved at the margins of the involved areas, was still defective. The extraneural disability consisted of slight and temporary impairment of the range of forearm extension and supination. The end result was complete restoration of function.

CASE 161.—S.P.J.F. was struck on the left arm by a flying object in an aircraft accident on January 8, 1943, and his humerous was fractured through the mid-third of the shaft. The nerve lesion was complete above the supply to the brachioradialis and the fibres of the posterior cutaneous nerve of the forearm were not damaged.

Recovery first appeared in the brachioradialis at 13 weeks and continued uninterruptedly until at 28 weeks all muscles were contracting. At 54 weeks all movements

were fully and strongly executed. The power of the grip was two-thirds that of the opposite side, and synergic extension of the wrist was only mildly affected. Cutaneous sensation was then normal. At this stage the patient was returned to full service duties. Radial nerve function was normal in every respect when he was again examined at 136 weeks. There was no extraneural disability at any stage. The end result was complete restoration of function.

CASE 232.—R.J.T. was involved in a truck accident on August 13, 1943, in which he sustained a fracture through the mid-third of the shaft of the right humerus with complete lesions of the median and radial nerves. The radial nerve was involved above the branches to the brachioradialis—the posterior cutaneous nerve of the forearm was not damaged.

Recovery appeared simultaneously in the *extensor carpi radialis longus*, *extensor carpi ulnaris* and *extensor digitorum communis* at eight and a half weeks, and three days later all the muscles supplied by the radial nerve were contracting. Motor function in the field of the radial nerve was fully restored at 31 weeks, when the residual motor disability was due entirely to the associated median nerve lesion. When the patient was last examined at 120 weeks cutaneous sensation, though improved, was still very defective. The extraneural disability consisted of slight and temporary impairment of the range of forearm extension and supination. The end result was complete restoration of function.

CASE 317.—W.G.R., on June 16, 1944, sustained a fracture through the mid-third of the shaft of the right humerus when he fell ten feet from scaffolding and struck his right arm on a joist. The nerve lesion was complete above the branches to the brachioradialis; the fibres of the posterior cutaneous nerve of the forearm were not damaged.

Recovery appeared in the brachioradialis at 16 weeks, and at 29 weeks all muscles were contracting. When the patient was last examined at 109 weeks all movements were fully and strongly executed. There was good synergic extension of the wrist and the power of the grip exceeded that on the opposite side. Burning pain was felt in the superficial radial field for five weeks. Cutaneous sensation commenced to recover at 20 weeks, following which the extent and depth of the defect were gradually reduced. When the patient was last examined there remained an area of defective sensation in the first web space which had persisted unchanged for 20 weeks. Stiffness in all joints below the elbow had followed continued immobilization of the limb for five weeks, but responded rapidly to treatment. The end result was complete restoration of function.

### *Lesions Due to Penetrating Injuries other than Gunshot Wounds.*

CASE 170.—J.G.W., on November 7, 1939, had his left elbow crushed between the buffers of a train and this resulted in a comminuted fracture of the head and neck of the radius, a posterior dislocation of the ulna, and complete lesions of the median and radial nerves at the elbow. At six weeks an abscess was drained at the site of injury. The head of the radius was excised in April, 1940. When the patient was first examined by me at 184 weeks there was a lesion of the radial nerve above the branches to the brachioradialis. The posterior cutaneous nerve of the forearm was not involved. Exploration four weeks later revealed that the nerve in the furrow had become converted into a firm, irregular fibrotic cord. A six-inch graft would have been required to bridge the gap following resection. Furthermore, so great was the destruction of soft tissues about the lateral humeral epicondyle that, even in the unlikely event of the nerve being satisfactorily repaired, the extraneural injury would severely limit restoration of function. Consequently no attempt was made to repair the nerve. When the patient was last examined, four years after the injury, the radial lesion was unchanged. The end result was no recovery.

CASE 180.—W.W., on March 10, 1943, sustained an oblique bayonet wound which entered the volar aspect of the right forearm 10·0 centimetres below the medial humeral epicondyle and emerged from the dorso-lateral aspect of the arm 7·5 centimetres above the lateral epicondyle. The wound was not infected, but the long flexor mass was lacerated with resultant moderate scarring. The radial nerve was explored in the furrow 38 days later, found to be severed above the branches to the brachioradialis and was sutured. The posterior cutaneous nerve of the forearm was independently severed and was not repaired.

Recovery commenced in the *extensor carpi radialis longus* 20 weeks after the suture and proceded uninterruptedly until all muscles were contracting a further 22 weeks later. When last examined, 52 weeks after the injury, the wrist could be fully extended against strong resistance, the fingers fully extended against mild resistance and radial abduction and extension of the thumb executed through a full range against weak resistance. The power of the grip was one-third that on the opposite side and

was aided by some synergic extension of the wrist. The efficiency of the grip was impaired by limitation of flexion of the ring and little fingers resulting from the injury to the digital flexors together with some shortening of the extensors. There was no improvement in cutaneous sensation in the fields of the posterior cutaneous nerve of the forearm and the superficial radial nerve. The patient was discharged and returned to his prewar occupation as a farmer. The end result was satisfactory.

CASE 195.—J.S. was injured in an aircraft accident on May 29, 1943. In addition to multiple injuries elsewhere, there was a small healed laceration over the course of the radial nerve in the mid-third of the arm 15·0 centimetres above the lateral epicondyle. There was a complete lesion of the radial nerve above the supply to the brachioradialis and the posterior cutaneous nerve of the forearm was involved. The wound was not infected.

Recovery commenced in the brachioradialis and *extensor carpi radialis longus* at 11 to 14 weeks and proceeded uninterruptedly for a further nine weeks, by which time all muscles were contracting. The patient returned to full flying duties 39 weeks after injury. At that time all movements controlled by the radial nerve could be fully and strongly executed. Pronation and flexion at the metacarpo-phalangeal joints were slightly limited consequent on a united fracture of the distal third of the ulna, a dislocation of the inferior radio-ulnar joint and some extensor shortening. There was good synergic extension of the wrist, but the power of the grip was one-third that on the opposite side. Cutaneous sensation commenced to recover at 27 weeks and was fully restored in the field of the posterior cutaneous nerve of the forearm eight weeks later. When the patient was last examined the residual sensory defect was confined to a narrow strip along the dorsum of the thumb, over which sensation to pin-prick and light touch was mildly impaired. The end result was good.

CASE 225.—H.J.P. The cause of the lesion in this patient was the removal, in January, 1941, of a neurofibroma from the nerve immediately above the branches to the brachioradialis with primary suture of the nerve. Twenty-eight weeks later secondary suture was performed. In the absence of any recovery tendon transplantations were prematurely undertaken 19 weeks after the secondary suture.

When the patient was first examined by me 121 weeks after the secondary suture, the *extensores carpi radiales*, *extensor digitorum communis* and *abductor pollicis longus* were contracting strongly and the brachioradialis weakly. It was not possible to estimate accurately the condition of the remaining muscles owing to the transplantations. Sensation was normal. Function was adversely, but not markedly, influenced by the tendon transplantations.

CASE 282.—I.G.G.C. sustained an ax injury on February 22, 1944, which resulted in a laceration of the dorsum of the right arm near the lower end of the spiral groove. At operation two hours later an almost completely severed radial nerve was sutured approximately 12·5 centimetres above the lateral epicondyle—the site of injury was above the branches to the brachioradialis. The posterior cutaneous nerve of the forearm was independently damaged.

Recovery was first observed in the brachioradialis 22 weeks after the suture and proceeded uninterruptedly for a further 23 weeks, by which time all muscles were contracting.

When the patient was last examined at 104 weeks, extension of the wrist, thumb and fingers could be fully and strongly executed. There was a mild paresis of radial abduction of the thumb, which was, however, full in range. The power of the grip was three-fifths that on the opposite side and there was some synergic extension of the wrist. There was no extraneural disability. There was no improvement in cutaneous sensation in the field of the superficial radial nerve, though there had been some reduction in the extent and depth of the sensory defect over the dorsum of the forearm. The end result was satisfactory.

### *Lesions Due to Gunshot Wounds.*

CASE 27.—J.E.L. sustained a shrapnel wound of the left arm on February 6, 1942. The wound of entry was centred at the mid-point of the posterior surface of the arm and screening revealed a small foreign body situated posteriorly at the junction of the mid-third and upper third of the arm. At operation the radial nerve was seen to be partially severed, but it was not sutured, nor was the foreign body removed. There was complete loss of function in the field of the nerve. The wound was not infected and residual scarring was insignificant. When the patient was first examined by me at nine weeks there was a complete loss of function distal to the *extensores carpi radiales*, which were contracting. Sensation in the field of the posterior cutaneous nerve of the forearm was normal. The brachioradialis was contracting—there was no note in the history as to when it had recovered. The *extensores carpi radiales* had shown signs of recovery three weeks after the injury. The *extensor digitorum*

*communis* and *abductor pollicis longus* commenced to contract at 13 weeks and the *extensor carpi ulnaris* and *extensor pollicis longus* at 19 and 21 weeks respectively. The only motor disability at 55 weeks was a slight residual paresis in the extensors of the index finger. At nine weeks there had been a subjective sensation of numbness in the superficial radial field, which was, however, hyperalgesic to pin-prick. The hyperalgesia gradually subsided, but when the patient was last examined sensation to both pin-prick and light touch were defective. There was no reduction in the area of sensory defect and there was no extraneural disability. The end result was good.

CASE 40.—K.H.McN. sustained a perforating machine-gun bullet wound of the right cubital fossa on November 19, 1941. The point of entry was marked by a circular scar in the cubital fossa immediately lateral to the margin of the biceps. The point of exit was marked by a vertical linear ragged scar which commenced just above the lateral epicondyle and extended upwards for 6·5 centimetres. Local destruction of muscle and a complete lesion of the radial nerve in the furrow below the upper branch to the brachioradialis. The wound was infected and there was considerable scarring in the supracondylar region. The posterior cutaneous nerve of the forearm was independently damaged.

Exploration at 44 weeks revealed a severed nerve. Both ends were embedded in scar tissue with a large proximal neuroma; these were freed, freshened and sutured.

Contraction was first observed in the *extensor carpi radialis longus* 20 weeks after suture. Regeneration proceeded in anatomical order until all muscles were contracting 20 weeks later. When the patient was last examined at 165 weeks, extension of the wrist, fingers and thumb could be fully and strongly executed. There was good synergic extension of the wrist and the power of the grip was one-half that of the opposite side. The range of radial abduction of the thumb was reduced by one-third, but the movement could be executed against fair resistance. There was no recovery of cutaneous sensation. Wrist and digital flexion were very slightly restricted by the extensor shortening and elbow extension limited by a few degrees. The end result was satisfactory.

CASE 64.—A.H.P. sustained a perforating bullet wound of the right arm on April 13, 1942. The point of entry was marked by a small circular scar in the lateral bicipital furrow, 8·0 centimetres above the medial epicondyle; the point of exit by a small circular scar on the dorsum of the arm 12·5 centimetres above the medial epicondyle. There was a complete lesion of the radial nerve at the distal end of the groove. The posterior cutaneous nerve of the forearm was not involved. The wound was not infected and residual scarring was insignificant.

Recovery was first observed in the *extensor carpi radialis longus* at 22 weeks. When the patient was next examined at 29 weeks all the remaining muscles were contracting, though the state of the thumb musculature suggested that recovery had only just appeared in that group. Motor function was fully restored at 55 weeks, when the patient was returned to active service. There was no improvement in cutaneous sensation. No extraneural disability was present. The end result was complete restoration of function.

CASE 69.—F.J. sustained a perforating bullet wound of the left arm above the lateral epicondyle on July 16, 1942. The entry and exit wounds were elongated and parallel and extended vertically upwards from the lateral epicondyle. The anterior wound was 11·0 centimetres in length and the posterior 17·5 centimetres. The wound was infected and there was considerable residual scarring in the supracondylar region. There was a complete lesion of the radial nerve below the supply to the brachioradialis.

Recovery first appeared in the *extensor digitorum communis* at 13 weeks and reached the *extensor pollicis longus*, the last muscle to be reinnervated at 25 weeks. The patient was returned to active service at 37 weeks with motor function just short of normal. Cutaneous sensation had commenced to recover at 25 weeks and was fully restored six weeks later. There was no extraneural disability. The end result was good—complete restoration of function was anticipated.

CASE 79.—T.R.D., on July 12, 1942, sustained multiple wounds from a mortar bomb involving the dorsal and lateral aspects of the arm from the axilla to the elbow. There was a complete lesion of the radial nerve approximately 10·0 centimetres above the lateral epicondyle. The posterior cutaneous nerve of the forearm was not involved. The wound was not infected and the residual scarring was insignificant.

All muscles were paralysed at four weeks, but when first examined by me at 18 weeks the brachioradialis and *extensores carpi radiales* were contracting feebly. The *abductor* and *extensor pollicis longus* were the last muscles to be reinnervated, having commenced to contract between 28 and 30 weeks. Motor function was fully restored at 58 weeks. Improvement in cutaneous sensation commenced at 23 weeks and when the patient was last examined at 58 weeks the area of disturbed sensation had been reduced to a small circular patch 2·0 centimetres in diameter in the first web.

Extraneural impairment of forearm extension of the elbow, supination of the forearm and flexion of the wrist had been corrected at 37 weeks. When the patient was last examined the residual extraneural disability was confined to the metacarpo-phalangeal joints, where flexion was limited by 45°. The end result was complete restoration of function.

CASE 97.—T.G.H. sustained multiple gunshot wounds of the left arm on December 1, 1942. There was a large, irregular, oval scar, 5·0 by 2·5 centimetres, above the lateral epicondyle, and another, 7·5 by 4·0 centimetres, directed upwards and outwards across the cubital fossa. These wounds marked the site of involvement of the radial nerve in which conduction was completely interrupted immediately below the supply to the brachioradialis. The posterior cutaneous nerve of the forearm was not damaged. The median and ulnar nerves had been concussed and the brachial artery had been ligated at operation. The wound responsible for the radial lesion was infected and there was considerable residual scarring.

Recovery was first observed in the *extensor carpi radialis longus* at 12 weeks. The *extensor carpi ulnaris* and *extensor digitorum communis* commenced to contract at 17 and 22 weeks respectively. The patient was then transferred to another State. At this stage there was no improvement in cutaneous sensation. Extraneural limitation of passive movement at the elbow and radio-ulnar joints had been corrected, but flexion of the wrist and metacarpo-phalangeal joints remained greatly limited. Subsequent inquiries revealed that he had been returned to service 58 weeks after the injury and was acting as an instructor in rifle and bayonet drill; the function of the arm was described as "normal". The end result was at least good or satisfactory.

CASE 114.—P.F. sustained a bullet wound of the left shoulder on January 5, 1943. The bullet entered just below the lesser tuberosity of the humerus and lodged on the dorsal surface of the scapula. It was subsequently removed. There was a complete lesion of the radial nerve below the most superior fibres to the triceps. The wound discharged for three months, but residual scarring was insignificant.

The triceps recovered rapidly from a severe paresis and was functioning normally at nine weeks; at this stage contractions appeared in the *extensor carpi radialis longus*. Nineteen weeks later the *extensor pollicis longus*, the last muscle to recover, had begun to contract.

At 106 weeks motor function was fully restored. Sensation on the dorsum of the forearm commenced to improve at 31 weeks and at 95 weeks the involved area had been reduced to a narrow strip along the mid-line. When the patient was last examined at 156 weeks there were scattered patches of defective sensation along this line. At that time there was some improvement in the quality of sensation in the field of the superficial radial nerve, but no reduction in the area involved. No extraneural disability. The end result was complete restoration of function.

CASE 185.—J.F.H.D. sustained a shrapnel wound of the left arm on April 24, 1943. The point of entry was marked by a small scar situated in the middle of the dorsum of the arm, 12·0 centimetres above the medial humeral epicondyle; the foreign body was retained. The wound was not infected and residual scarring was insignificant. There was a complete lesion of the radial nerve above the brachioradialis. The posterior cutaneous nerve of the forearm was not involved.

Recovery first appeared in the brachioradialis at 14 weeks and by 30 weeks all the remaining muscles were contracting. Motor function was fully restored at 61 weeks. At that time there remained some scattered foci of disturbed sensibility in the field of the superficial radial nerve. No extraneural disability was present. The end result was complete restoration of function.

CASE 202.—J.W.McK. sustained a gunshot wound of the right arm on August 4, 1943. There was a large wound extending along the course of the radial nerve from the cubital crease line to a point 14·0 centimetres above the lateral epicondyle. The radial nerve and a branch to the brachioradialis had been observed in the wound and reported intact. The wound was infected and the residual scarring was considerable. There was complete motor and sensory loss in the field of the radial nerve; the posterior cutaneous nerve of the forearm was independently involved.

Contraction was first observed in the *extensor digitorum communis* at eight weeks and at 14 weeks all muscles were contracting. The patient returned to service at 33 weeks with motor function just short of normal. There was a mild residual paresis of the *abductor* and the *extensor pollicis longus*. The power of the grip was four-fifths that on the opposite side and there was good synergic extension of the wrist. Cutaneous sensation had not improved. There was no extraneural disability. The end result was good—complete restoration of function was anticipated.

CASE 203.—J.W.K. sustained a grenade wound of the right arm on September 8, 1943. The wound extended vertically upwards for 7·0 centimetres from a point 6·0 centimetres above the lateral humeral epicondyle. The radial nerve had been observed

in the wound just below the point where it passed anterior to the intermuscular septum—it was described as "contused with a superficial laceration". There was complete interruption of conduction in the nerve. The wound was not infected and the residual scarring was insignificant.

Recovery commenced in the brachioradialis and *extensor carpi radialis longus* at 20 weeks. At 31 weeks the remaining muscles were contracting. Motor function was completely restored at 65 weeks. Cutaneous sensation commenced to improve at 39 weeks. When the patient was last examined at 146 weeks the area of impaired sensation was reduced to a small patch in the first web space. No extraneural disability was present. The end result was complete restoration of function.

CASE 244.—R.J.A. sustained multiple wounds of the right arm from a grenade injury on December 12, 1943, resulting in complete paralysis of the radial nerve. Immediate exploration of the wounds on the dorsum of the arm towards the lower part of the spiral groove revealed the radial nerve to be traumatized and hæmorrhagic, but in continuity. The posterior cutaneous nerve of the forearm was not involved. The wound was not infected and the residual scarring was insignificant.

Recovery first appeared simultaneously in the brachioradialis and *extensor carpi radialis longus* at six weeks. The *extensor carpi ulnaris* and *extensor digitorum* communis commenced to contract at 28 weeks. The thenar group was still paralysed at 29 weeks. The patient was next examined at 46 weeks, when all muscles were contracting. Motor function was fully restored at 64 weeks. Cutaneous sensation commenced to improve between 29 and 46 weeks, and at 120 weeks, though the area had not been reduced, the quality of sensation was very nearly normal everywhere except in a patch 2·0 centimetres in diameter in the first web space, where sensation was very defective. No extraneural disability was present. The end result was complete restoration of function.

CASE 248.—W.R.L. sustained a shrapnel wound on December 6, 1943, involving the inner aspect of the right arm at the axillary outlet. Wide excision for gas gangrene resulted in extensive scarring at the axillary outlet and down the inner aspect of the arm. There was a complete lesion of the radial nerve below the branches to the triceps and a partial lesion of the ulnar nerve. Plastic operations to the axilla and arm at 22 weeks revealed that the radial nerve had been completely severed in the brachio-axillary angle. After being freshened the ends were sutured under tension. In the absence of any recovery 67 weeks later appropriate tendon transplantations were performed. The end result was no recovery.

CASE 255.—F.H.F. sustained a mortar bomb wound of the left arm on December 9, 1943. The point of entry was marked by a scar, 7·0 centimetres in length, extending upwards along the postero-lateral aspect of the arm from a point 4·0 centimetres above the lateral epicondyle; the point of exit by an oval scar, 5·0 centimetres in length, which commenced at the cubital crease and extended proximally along the lateral margin of the biceps. The radial nerve was involved in the furrow above the branches to brachioradialis and paralysis was complete. The posterior cutaneous nerve of the forearm was not damaged. The wound was infected and the resultant scarring considerable.

Recovery commenced in the brachioradialis and *extensor carpi radialis longus* at eight weeks. At 26 weeks the *extensor pollicis longus*, the last muscle to be reinnervated, was contracting. When the patient was last examined at 115 weeks all movements were fully and strongly executed with good synergic extension of the wrist. The power of the grip was three-fourths that on the opposite side. The quality of cutaneous sensation commenced to improve between 34 and 38 weeks; there was no reduction, however, in the area involved. At 57 weeks there was still some disturbance of sensation over the original area involved, and this has persisted unchanged. No extraneural disability was present. The end result was good—complete restoration of function is anticipated.

CASE 264.—J.R.E. sustained a perforating bullet wound of the right elbow on January 22, 1944. The point of entry was marked by a vertical linear scar, 5·0 centimetres long, crossing the cubital crease anterior to the medial epicondyle; the point of exit by a linear scar, 6·0 centimetres long, situated anterior to the lateral epicondyle and at right angles to the cubital crease line. The median nerve had been reported "almost completely severed" and the radial nerve "completely severed in the anterior compartment of the arm". The nerves had not been repaired. The wounds were mildly infected and healing resulted in a large adherent scar in the region of the epicondyle. There was complete paralysis of the radial nerve below the supply to the brachioradialis. The posterior cutaneous nerve of the arm was not damaged.

Contraction commenced in the *extensor carpi radialis longus* at 14 weeks, indicating that spontaneous regeneration was occurring. At 34 weeks all the remaining muscles were contracting. Motor function was fully restored at 86 weeks. Cutaneous sensation

commenced to improve in quality at 26 weeks, but at 125 weeks there remained some lessening of sensory acuity over an area substantially the same as that originally charted. Successive examinations had indicated that little further improvement was to be expected. There was no extraneural disability. The end result was complete restoration of function.

### *Lesions of the Radial Nerve Due to Gunshot Wounds which Result in a Fracture of the Humerus.*

CASE 15.—L.A.L. sustained a shrapnel wound of the lower third of the left arm on May 30, 1941, with a transverse fracture of the shaft of the humerus 7·5 centimetres above the elbow. The point of entry was marked by a small circular scar over the lateral supracondylar ridge, 8·0 centimetres above the lateral epicondyle; the point of exit by a small scar immediately above and behind the lateral epicondyle. The wound had been infected and healed with significant scarring in the neighbourhood of the nerve. At one week a complete lesion of the radial nerve above the branches to the brachioradialis had been recorded. No further information was provided. When first examined by me at 31 weeks all muscles were contracting against resistance, though the range of all movements of the wrist and fingers had been considerably impaired by prolonged immobilization. There remained some paresis of the radial muscles at 95 weeks, but when the patient was next examined at 161 weeks the only disability was restriction of flexion at the metacarpo-phalangeal joints, which was due solely to irreparable extraneural changes. The power of the grip was half that on the opposite side. There had been no improvement in cutaneous sensation in the field of the superficial radial nerve. The end result was good.

CASE 18.—R.H. sustained a perforating bullet wound through the middle of the right arm on June 10, 1941, with a comminuted fracture of the mid-third of the humerus. The point of entry was situated anteriorly, at the point where the lower border of the tendon of *pectoralis major* comes into contact with the deltoid; the point of exit was situated postero-laterally behind the lower limit of insertion of the deltoid. There was a complete lesion of the radial nerve in the spiral groove above the supply to the brachio-radialis—the posterior cutaneous nerve of the forearm was involved. Though infected, the wound had healed with little scarring.

At 23 weeks there was no recovery and prolonged immobilization had resulted in stiffness which restricted all movements at and below the elbow. At 30 weeks all the muscles, with the exception of the brachioradialis, were contracting feebly, and at 35 weeks the relevant movements could be executed against resistance. There was no recovery in the brachioradialis at 51 weeks, but this muscle was contracting when the patient was next examined at 67 weeks.

When the patient was last examined at 191 weeks all movements were fully and strongly executed. There was good synergic extension of the wrist and the power of the grip was three-fourths that on the opposite side. Recovery of sensation in the field of both cutaneous nerves did not commence until 115 weeks; at 191 weeks its acuity remained considerably reduced over the whole of the original area. The extraneural impairment of mobility had been fully corrected at 89 weeks. The end result was good.

CASE 39.—P.L.S. sustained a perforating shrapnel wound of the right arm on June 17, 1941, which resulted in a grossly comminuted fracture of the upper half of the humerus with extensive loss of bone and soft tissues. There was a complete lesion of the radial nerve below the upper branches to the triceps. Severe infection delayed exploration of the nerve for more than a year. Residual scarring was considerable. A bone graft was inserted with a good result. The lesion was still complete at 90 weeks, when the nerve was explored from the axilla to the spiral groove. Throughout this part of its course it was frayed, thinned, and involved in dense scar tissue. Fibrosis of the nerve could be traced high into the axilla. Attempts to free the nerve from surrounding scar tissue resulted in the destruction of the separate and intact fibres to triceps—these were conducting before mobilization of the nerve, but not after it. In view of the long-standing history of infection, the delicate nature of the bony union and the length of the nerve involved, attempts at repair were abandoned. Tendon transplantations were performed later. The condition was unchanged at 165 weeks. The end result was no recovery.

CASE 59.—W.A.G. was hit by a fragment of a mortar shell in the right arm on June 12, 1941, and this resulted in a comminuted fracture of the upper third of the humerus. The point of entry was an oval depressed scar, 5·0 by 2·5 centimetres, at the mid-point of the anterior margin of the deltoid. The wound was mildly infected; residual scarring was insignificant. Radial and median nerve lesions were recorded, the notes stating that the radial nerve lesion was complete nine weeks after the injury and that there was no "wrist" drop at 16 weeks. When the patient was first

examined by me at 63 weeks all muscles supplied by the radial nerve were paresed, but at 84 weeks they had fully recovered. Sensation in the field of the posterior cutaneous nerve of the forearm was normal at my first examination, but that of the superficial radial nerve remained defective at 165 weeks; it had improved for a time and then became stationary. At 17 weeks there had been marked stiffness at and below the elbow, but at 63 weeks there remained only slight limitation of elbow extension (20°), supination (mild) and wrist extension (10°). The extraneural disability was fully corrected at 139 weeks. The end result was complete restoration of function.

CASE 72.—T.J.P. sustained a shrapnel wound of the left arm on July 22, 1942, resulting in an oblique fracture of the mid-third of the humerus. The point of entry was marked by a depressed irregular vertical scar, 2·5 centimetres long, superficial to the furrow 7·5 centimetres above the lateral epicondyle. The point of exit was marked by a small circular scar, at the antero-medial border of the biceps, 15·0 centimetres above the medial epicondyle. Numerous small metallic foreign bodies were retained in the lower part of the arm. There was no infection and the residual scarring was insignificant. The nerve was injured above the fibres to the brachioradialis and the lesion was reported to be complete. When the patient was first examined by me at 15 weeks there was a complete loss of function below the brachioradialis, which was contracting weakly; there was no note in the history as to when this muscle had recovered. The fibres of the posterior cutaneous nerve of the forearm were involved. Recovery appeared in the *extensor carpi radialis longus* at 20 weeks. Ten weeks elapsed before the patient was again available for examination, and by this time all muscles were contracting against resistance which varied in degree from strong in the case of the extensors of the wrist to gravity only in the case of the *abductor pollicis longus*, which had apparently only just recovered. Motor function was fully restored at 52 weeks. Sensation in the field of the superficial radial nerve was restored to normal at 20 weeks. When the patient was last examined the forearm area over which sensation was impaired had been considerably reduced. An extraneural disability was present and early limitation of passive movements at and below the elbow was fully corrected at 30 weeks. The end result was complete restoration of function.

CASE 81.—A.M.P. sustained a perforating bullet wound of the upper third of the left arm on July 11, 1942, resulting in a comminuted fracture at the junction of the middle and upper thirds of the humerus. At the point of entrance there was an irregular depressed scar on the inner aspect of the arm, just below the posterior axillary fold. The point of exit was marked by an irregular vertical scar at the mid-point of the lateral aspect of the arm. The wound was mildly infected; residual scarring was negligible. The records disclosed that a complete lesion of the radial nerve above the supply to brachioradialis but sparing the posterior cutaneous nerve of the forearm, had persisted for at least seven weeks. When the patient was first examined by me at 19 weeks, all the muscles supplied by the radial nerve could be contracted against weak resistance. The patient returned to duty at 38 weeks, when the only residual motor disability was a mild weakness of the finger extensors. Cutaneous sensation commenced to improve at 24 weeks, and when the patient was last examined the area of disturbed sensation had been reduced to a small patch over the dorsum of the thumb. As a result of prolonged immobilization in the initial stages all movements at and below the elbow had been limited to a few degrees, but at 37 weeks all movements except supination had shown improvement. Residual extraneural disability comprised mild limitation of forearm extension and supination. The end result was good—complete restoration of function is anticipated.

CASE 99.—A.H. sustained a perforating bullet wound of the left arm on October 26, 1942, which caused a comminuted fracture of the shaft of the humerous, at the junction of the middle and upper thirds, with a complete lesion of the radial nerve below the supply to the triceps. The posterior cutaneous nerve of the forearm was not involved. The point of entry was marked by a small circular depressed scar, situated on the mid-line of the dorsum of the arm, 20·0 centimetres above the medial epicondyle; the point of exit by a similar scar on the inner aspect of the arm, approximately 2·0 centimetres below the lower margin of the tendon of the *pectoralis major*. The wound was infected and the residual scarring in the vicinity of the radial nerve was considerable.

Recovery was first observed in the *extensor carpi radialis longus* at 24 weeks. Within the period 26 to 28 weeks all muscles but the *extensor pollicis longus* had commenced to contract—this showed signs of recovery at 33 weeks. When the patient was last examined at 112 weeks, movements controlled by the radial nerve were fully and strongly executed. There was good synergic extension of the wrist and the power of the grip was one-half that on the opposite side. Sensation in the field of the superficial radial nerve had improved, but was still defective. On the first examination at 13 weeks movements at and below the elbow joint had been severely impaired by extraneural changes due to immobilization. Residual extraneural disability comprised

30° of limitation of extension at the elbow joint, 15° of limitation of wrist extension and flexion, and approximately 25° of limitation of flexion at the metacarpo-phalangeal joints. The end result was good.

CASE 100.—S.C. sustained a perforating bullet wound of the lower third of the left arm on November 29, 1942, resulting in a comminuted fracture of the shaft of the humerus at the junction of the middle and lower thirds. The point of entry was marked by a small circular scar situated 5·0 centimetres immediately above the lateral epicondyle; the point of exit by a large, irregular, depressed scar, 8·0 centimetres in length, extending upwards along the medial surface of the arm from a point 5·0 centimetres above the medial epicondyle. There was a complete lesion of the radial nerve immediately below the upper fibres to the brachioradialis, which was contracting weakly. The posterior cutaneous nerve of the forearm was involved separately and there was an associated complete lesion of the ulnar nerve. Small sinuses continued to discharge and sequestra required removal periodically for twelve months after the injury. Residual scarring was considerable.

Recovery first appeared in the *extensor carpi radialis longus* at 23 weeks. A further 13 weeks elapsed before the last muscle to be reinnervated was contracting. Motor function (radial nerve) was fully restored at 112 weeks and cutaneous sensation in the field of the posterior cutaneous nerve of the forearm had recovered at 94 weeks. The first signs of recovery of the superficial radial nerve appeared between 60 and 80 weeks, but when the patient was last examined at 175 weeks, sensation remained defective over the same area as that first charted. Immobilization in the early stages resulted in the limitation of all movements at and below the elbow to a few degrees, but this disability was fully corrected at 45 weeks. The end result was complete restoration of function.

CASE 106.—K.N.M. sustained a perforating bullet wound of the right arm on December 1, 1942, resulting in a comminuted fracture of the lower third of the shaft of the humerus with lesions of the radial, median and ulnar nerves. The point of entry was marked by a small circular scar just above and behind the lateral epicondyle; the point of exit by a small circular scar 2·5 centimetres below and just anterior to the lower margin of the tendon of *latissimus dorsi*. Severe infection with considerable residual scarring was present. When the patient was first examined by me nine weeks after the injury there was a complete lesion of the radial nerve above the branches to the brachioradialis. The posterior cutaneous nerve of the forearm was separately involved. The nerve appeared to have been injured approximately 5·0 centimetres above the lateral epicondyle. Regeneration was advanced in the median and ulnar nerves and the evidence supported the belief that these nerves had only been concussed. Owing to extraneural changes, movements at and below the elbow were limited to a few degrees.

Recovery first appeared in the brachioradialis at 17 weeks and by 19 weeks later all muscles were contracting. Motor function (radial nerve) was normal at 100 weeks and there was good synergic extension of the wrist. The power of the grip was one-half that on the opposite side; the impaired power was due to extraneural changes and particularly to the limited flexion at the metacarpo-phalangeal joints. Sensation commenced to improve on the dorsum of the forearm at 52 weeks, but had not fully recovered when the patient was last examined at 190 weeks. At this time the superficial radial nerve showed only minimal recovery. The extraneural disability had shown great improvement and involved only a few degrees of limitation of most of the movements at and below the elbow. The end result was complete restoration of function.

CASE 107.—R.D.S. sustained a perforating bullet wound of the right arm on July 16, 1942, resulting in a transverse fracture of the shaft of the humerus at the junction of the middle and lower thirds. The point of entry was marked by an irregular circular scar 10·0 centimetres above the tip of the olecranon and just lateral to the median plane; the point of exit by an oblique linear scar, 6·0 centimetres long, at the middle of the inner aspect of the arm. The wound had been infected and the residual scarring was considerable. The records contained no mention of nerve injuries, but when the patient was first examined by me at 29 weeks he displayed a complete lesion of the ulnar nerve and a recovering lesion of the radial nerve, in which all muscles below and including the brachioradialis were contracting to give a small range of movement against gravity. The posterior cutaneous nerve of the forearm had not been involved. Extraneural changes considerably impaired the range of all movements. Motor function (radial nerve) was restored to normal at 83 weeks, and at 147 weeks the residual motor disability was due to the ulnar lesion and to extraneural changes which slightly limited flexion at the metacarpo-phalangeal joints. Cutaneous sensation, though slightly improved, was still very defective—there was no reduction of the involved area. The end result was complete restoration of function.

CASE 117.—L.A.H. sustained a perforating bullet wound through the left arm on December 13, 1942, resulting in a fracture of the shaft of the humerus at the junction

of the middle and lower thirds. The point of entry was marked by a circular scar, 1·0 centimetre in diameter, at the inner margin of the biceps, 7·5 centimetres above the medial epicondyle; the point of exit by a large irregular scar centred 7·5 centimetres directly above the lateral epicondyle. The wound had been infected and the residual scarring was considerable. There was complete loss of radial nerve function at and below the brachioradialis.

When the patient was first examined by me nine weeks after the injury, all muscles supplied by the radial nerve were contracting. Wrist and finger extension could be carried out through a few degrees against weak resistance, while a flicker of extension and radial abduction of the thumb could be executed. The posterior cutaneous nerve of the forearm was not involved. Joint movements below and including the elbow were severely impaired by extraneural changes. All movements controlled by the radial nerve could be fully and strongly executed at 76 weeks. There was fair synergic extension of the wrist and the power of the grip was a little more than half that on the opposite side. A circular area in the first web, approximately 3·0 centimetres in diameter, remained dull to pin-prick and insensitive to light touch. A residual extraneural defect was present—the elbow could not be extended beyond a right angle. When the patient was last examined at 108 weeks the condition was unchanged. The end result was good.

CASE 118.—F.C.J. sustained a gunshot wound of the right elbow region on October 29, 1942; this resulted in a fracture of the humerus at the junction of the middle and lower thirds of the shaft. The point of entry was marked by a circular scar, 2·0 centimetres in diameter, just below the lateral epicondyle; the point of exit by a vertical scar, 2·5 centimetres long, situated 10·0 centimetres above the medial epicondyle. The wound was infected and the residual scarring significant. There was a complete lesion of the radial nerve about 9·0 centimetres above the lateral epicondyle. The posterior cutaneous nerve of the forearm was not involved. Recovery first appeared in the brachioradialis at 16 weeks. At 20 weeks the three wrist extensors and the *extensor digitorum communis* were contracting and they were followed by the abductor and *extensor pollicis longus* at 28 weeks. At 38 weeks the patient was discharged from hospital. At that time wrist extension was normal, the thumb and fingers could be fully extended against gravity and fair resistance, while the thumb could be radially abducted against gravity and weak resistance through a range just short of normal. There had been no sensory recovery. There was no extraneural disability. The end result was satisfactory—complete restoration of function is anticipated.

CASE 128.—J.S. sustained a perforating bullet wound of the left arm on October 29, 1942, with complete destruction of the upper third of the shaft of the humerus. The point of entry was marked by a small depressed scar on the inner aspect of the arm, 5·0 centimetres below the posterior brachio-axillary angle; the point of exit by an extensive irregular linear scar, 17·5 centimetres long, extending down the outer aspect of the arm. Soft tissue loss and residual scarring were considerable. There was a complete lesion of the radial nerve below the upper fibres to the triceps; the posterior cutaneous nerve of the forearm was involved. Prolonged infection delayed bone grafting and exploration of the nerve. At 85 weeks satisfactory union of the humerus had followed bone grafting. Exploration of the nerve at 93 weeks revealed conditions which were unfavourable for repair or grafting. The lesion was still complete at 105 weeks. The end result was no recovery.

CASE 134.—W.W. sustained a perforating gunshot wound of the middle third of the right arm on January 12, 1943, and this resulted in a fracture of the middle third of the shaft of the humerus. The point of entry was marked by a vertical depressed scar, 12·5 centimetres long, on the outer aspect of the middle third of the arm; the point of exit by a vertical depressed scar extending down the postero-medial aspect of the arm from the posterior axillary fold. There was a complete lesion of the radial nerve involving the brachioradialis and the posterior cutaneous nerve of the forearm. Soft tissue and bone infection delayed exploration of the nerve, which was carried out 39 weeks after the injury. The residual scarring was considerable. The nerve was exposed from the spiral groove to the lateral epicondyle. It appeared normal, but did not respond to electrical stimulation. At the distal end of the groove the nerve was acutely angulated round a sharp spur of bone and above this it was lost in dense scar tissue. The adherent nerve was freed with difficulty, and just above the spur of bone pus was found. Adequate resection and suture being impossible, grafting was decided upon; the nerve was divided below the scarred section and the distal segment was transferred to the inner aspect of the arm between the biceps and brachialis muscles. Nine weeks later the nerve was exposed in the brachio-axillary angle and freed distally as far as the scarred zone. It was sectioned at the appropriate level and joined to the distal segment by means of a 6·0 centimetre cable graft (obtained from the patient's lateral cutaneous nerve of the thigh and the medial cutaneous nerve of the arm). When the patient was last examined 58 weeks after grafting

there were no signs of regeneration, and tendon transplantations were recommended. There was no extraneural disability. The end result was no recovery.

CASE 140.—G.A. sustained a perforating shrapnel wound of the left arm on July 22, 1942; this resulted in a comminuted fracture of the lower third of the shaft of the humerus. The point of entry was marked by an irregular depressed scar, 10·0 centimetres above the lateral epicondyle; the point of exit by an irregular scar involving most of the inner aspect of the arm. Severe infection took place with considerable residual scarring. There was a complete lesion of the radial nerve, involving the brachioradialis, while the posterior cutaneous nerve of the forearm was independently involved. Infection delayed exploration of the nerve, which was not performed until 76 weeks after the injury. The nerve could not be repaired and tendon transplantations were carried out later. The end result was no recovery.

CASE 151.—L.G.C. sustained a perforating bullet wound of the upper third of the right arm on January 18, 1942; this resulted in a comminuted fracture of the upper third of the right humerus. There was a complete lesion of the radial nerve below the upper fibres to the triceps; the posterior cutaneous nerve of the forearm was involved. The wound was infected and residual scarring was considerable.

The nerve was explored in the spiral groove at 34 weeks. It was involved in dense scar tissue, through which it could not be traced. At least two branches to the triceps were said to arise proximal to the lesion. There was no neuroma either proximal or distal to the mass of scar tissue. A cord of scar tissue containing the nerve was freed and placed in a new muscular bed.

When the patient was first examined by me at 63 weeks, the lesion was still complete and further exploration was recommended with a view to resection and suture. The nerve was reexplored at 83 weeks, but conditions proved unfavourable for suture or grafting, and tendon transplantations were recommended. When the patient was last examined at 208 weeks the condition of the nerve was unchanged. The end result was no recovery.

CASE 175.—L.McP.F. sustained a perforating bullet wound of the left arm on March 22, 1942; this resulted in a comminuted fracture of the shaft of the humerus at the junction of the middle and lower thirds. The point of entry was marked by a small circular scar on the volar surface of the arm 12·0 centimetres above the cubital crease; the point of exit by a circular scar 9·0 centimetres above the medial epicondyle. The wound was infected, but there was little residual scarring. The only reference to nerve injuries in the patient's records was to the effect that on June 22, 1942, there was a "wrist drop with marked weakness of the extensors of the wrist". The patient was first examined by me at 63 weeks, when there was a flicker of contraction in the brachioradialis and the *extensores carpi radiales*; the *extensor carpi ulnaris* was paralysed, and the contribution of the *extensor digitorum communis* to the index finger was the only segment of that muscle contracting, while the relevant thenar movements were reduced in range and power by one-third. There was no disturbance of cutaneous sensation in the field of the radial nerve. There were also motor and sensory signs indicating mild impairment of ulnar nerve conduction. Contraction first appeared in the *extensor carpi ulnaris* at 82 weeks. When the patient was last examined at 204 weeks wrist extension could be fully carried out against strong resistance; the index and little fingers could be fully extended against fair resistance, and the middle and ring fingers to within 25° of the straight position, while thumb movements were normal in range and power. On contraction the brachioradialis was as prominent as on the opposite side. There was some synergic extension of the wrist, and the power of the grip was one-half that on the opposite side. There was no extraneural disability. The end result was satisfactory.

CASE 205.—A.W.M. sustained a shrapnel wound of the left arm on July 21, 1943; this resulted in an oblique fracture of the shaft of the humerus at the junction of the middle and lower thirds. There was a vertical linear scar, 9·0 centimetres long, extending upwards from a point 2·5 centimetres above the lateral epicondyle. A completely severed radial nerve was seen in the wound; the proximal end could not be found. Severe infection delayed exploration until the forty-sixth week. Residual scarring was considerable. The nerve was exposed by dissection through dense scar tissue. Between the neuromatous nerve ends there was a gap of 3·0 centimetres which would have been extended to 7·0 centimetres after appropriate preparation of the nerve ends. Repair of the nerve was abandoned and the patient was referred for tendon transplantations. There was no disturbance of cutaneous sensation, indicating that the field usually innervated by the radial nerve had an anomalous supply. The end result was no recovery.

CASE 209.—E.J.G. sustained a gunshot wound of the upper third of the left arm on September 15, 1943; this resulted in a comminuted fracture of the upper third of

the left humerus. There was a complete lesion of the radial nerve below the supply to the triceps. Four weeks later the condition was unchanged and the patient was transferred to another State. No further records are available.

CASE 214.—J.A.W. sustained a perforating bullet wound of the middle third of the right arm on September 5, 1943, with a comminuted fracture of the humerus at the junction of the upper and middle thirds of the shaft and a transverse linear fracture at the junction of the middle and lower thirds of the shaft. The point of entry was marked by a vertical linear scar, 4·0 centimetres long, at the anterior border of the insertion of the deltoid; the point of exit by an irregular depressed scar, slightly oblique, 10·0 centimetres long, commencing 12·5 centimetres above the medial epicondyle and extending upwards along the dorsum of the arm. Extensive soft tissue injury and prolonged infection took place, with considerable residual scarring. There was a complete lesion of the radial nerve involving the brachioradialis, but not the posterior cutaneous nerve of the forearm.

Recovery appeared in the brachioradialis and *extensor carpi radialis longus* at three weeks and progressed so rapidly that all muscles were contracting at six weeks. At an operation, 23 weeks after the injury, for the removal of sequestra from the upper fracture site, the radial nerve was seen crossing a cavity in the bone. It appeared normal in every respect. Motor function was just short of normal at 60 weeks. All movements were fully and powerfully executed and there was good synergic extension of the wrist. The average dynamometer readings for the grip were 270 for the right side and 330 for the left. At that time there had been no reduction in the field of cutaneous sensory disturbance, though within this area sensation had improved; recovery had commenced at 27 weeks. There was no extraneural disability.

The patient refractured his humerus 67 weeks after the injury and non-union had to be corrected with a bone graft. Though this injury did not impair the motor function of the radial nerve, it completely interrupted conduction in its sensory fibres, which comprised the posterior cutaneous nerve of the forearm and the superficial radial nerve. When the patient was last examined, 150 weeks after the injury, motor function was normal in every respect; sensation had improved temporarily over the dorsum of the forearm and in the field of the superficial radial nerve, but was still defective in both fields.

CASE 221.—W.J.W. sustained a shrapnel wound of the right arm on August 19, 1943, with a comminuted fracture of the middle third of the humerus. The point of entry was marked by a circular depressed scar at the anterior margin of the deltoid opposite the lower margin of the *pectoralis major*; the point of exit by a curved scar 11·5 centimetres long, extending downwards from the axilla along the postero-medial aspect of the arm. Two small metallic foreign bodies were retained in the soft tissues anterior to the fracture. There was a complete lesion of the radial nerve below the supply to the triceps, while the posterior cutaneous nerve of the forearm was involved. Persistent infection delayed exploration of the nerve until the thirty-eighth week. Local scarring was considerable. The nerve was exposed in the brachio-axillary angle and when traced distally was found to end in a bulb at the entrance to the spiral groove. The lower end was not found. The nerve was then exposed in the furrow and traced upwards until it ended in dense scar tissue in the groove. It was divided and the distal segment was transferred to the inner aspect of the arm between the biceps and brachialis muscles. The upper and lower ends were then sutured under light tension on the medial side of the arm. When the patient was last examined 50 weeks after suture there was no evidence of any regeneration. Wrist movements and flexion at the metacarpo-phalangeal joints were restricted by joint stiffness. The end result was no recovery.

CASE 231.—J.W.A. sustained a perforating gunshot wound of the right arm on August 24, 1943; this resulted in a comminuted fracture of the middle third of the shaft of the humerus. The point of entry was marked by a circular depressed scar, 2·5 centimetres in diameter, situated on the dorsum of the arm 16·0 centimetres above the medial epicondyle; the point of exit by a ragged depressed scar, 12·0 centimetres long, over the antero-lateral aspect of the arm, reaching within 12·5 centimetres of the lateral epicondyle. There was extensive injury to soft tissues and the field notes stated that "the radial nerve was torn and a piece blown away. The proximal end is lying in the wound and terminates at level of upper end of humerus." When the patient was first examined by me at 15 weeks there was a complete lesion of the nerve involving the brachioradialis and the posterior cutaneous nerve of the forearm. On the basis of the field report, exploration of the nerve was recommended, but infection prevented this until 26 weeks after the injury. Local scarring was considerable. The nerve was exposed in the middle and distal thirds of the arm; it appeared healthy and was not involved in scar tissue. Electrical stimulation gave contraction of the brachioradialis. It was inferred that the nerve could not have been severed and that

spontanous regeneration was taking place. The nerve was left undisturbed and the wound closed.

Voluntary contraction did not appear in the brachioradialis until 40 weeks after the injury, that is, 14 weeks after it was obtained by electrical stimulation of the nerve at operation. Recovery then proceeded uninterruptedly and in anatomical order until at 56 weeks all muscles were contracting. The power steadily improved until, at 77 weeks, all movements could be fully executed against resistance and the power of the grip was one-third that on the opposite side. At this stage there had been slight improvement in cutaneous sensation. The function of the thenar and digital muscles then gradually deteriorated and the nerve was reexplored at 102 weeks. The exposed nerve was traced proximally until a bulb was revealed in scar tissue which was adherent to the bone at the lower end of the spiral groove. The nerve above the bulb appeared to run through the humerus, but this proved to be only an extension of scar tissue. Some bone had been removed before it was realized that the nerve was not passing through the humerus. Following neurolysis the nerve was free and slack, and on electrical stimulation conducted impulses to all the muscles. When the patient was last examined, 19 weeks later, recovery was proceeding, though the residual paresis of the thumb was severe. The power of the grip was two-fifths that on the opposite side and there was no synergic extension of the wrist. The state of cutaneous sensation persisted unchanged. There was no extraneural disability. The end result was satisfactory.

CASE 234.—J.J.G. sustained a perforating bullet wound of the left arm on November 8, 1943; this resulted in a comminuted fracture of the middle third of the shaft of the humerus with considerable bone loss. The point of entry was marked by a linear scar on the medial aspect of the arm along the course of the neuro-vascular bundle, its middle point being 14·0 centimetres above the medial humeral epicondyle. At the point of exit there was an irregular oval depressed scar on the outer aspect of the arm 12·5 centimetres above the lateral epicondyle. There was a complete lesion of the radial nerve involving the brachioradialis and the posterior cutaneous nerve of the forearm. The wound was not infected and subsequent scarring was insignificant. There was an associated partial lesion of the median nerve in the middle of the arm.

Recovery first appeared in the brachioradialis and *extensor carpi radialis longus* at six weeks, and at 14 weeks all muscles were contracting. Radial motor function was fully restored at 32 weeks, when the residual disability was due to persistence of the median lesion and to extraneural changes (limited supination and elbow extension). Forty-five weeks after the injury there had been no improvement in cutaneous sensation. The end result was complete restoration of function.

CASE 243.—J.H.B. sustained a perforating gunshot wound of the left arm on August 17, 1943; this resulted in a comminuted fracture of the lower third of the shaft of the humerus. The point of entry was marked by a linear scar, 7·5 centimetres long, extending upwards from the medial epicondyle; the point of exit by a large irregular scar (9·0 by 4·0 centimetres) involving the lateral supracondylar region and the outer aspect of the cubital fossa. Extensive soft tissue injury and prolonged infection took place with considerable residual scarring. The ulnar nerve had been completely severed above the medial epicondyle and was sutured at the time of the injury. A complete lesion of the radial nerve was recorded, though the nerve had not been inspected. The posterior cutaneous nerve of the forearm was independently involved.

When the patient was first examined by me at 20 weeks the lesions of the radial and ulnar nerves were complete, the former being injured above the branches to the brachioradialis. Exploration of the nerve was delayed by infection. Spontaneous recovery appeared in the brachioradialis at 43 weeks. The nerve was explored in the furrow two weeks later. About midway between the point where it passed anterior to the intermuscular septum and the epicondyle, the nerve entered scar tissue and what appeared to be a swollen neurogliomatous-looking formation which extended to a point just above the epicondyle. Just distal to this mass branches passed laterally to the brachioradialis and *extensor carpi radialis longus* and medially to the brachialis; stimulation of the latter produced contraction of the lateral fibres of the muscle. Stimulation of the nerve above the mass gave only weak contraction of the brachioradialis. The scarred zone and neurogliomatous mass were excised and the nerve ends were freshened and sutured. The nerve to the brachialis was sacrificed. The suture line was situated in an unfavourable field just above the lateral epicondyle at a point immediately above that at which the branches were passing laterally from the trunk; a satisfactory bed could not be prepared for the nerve. Recovery appeared in the brachioradialis and *extensor carpi radialis longus* 23 weeks after suture. Fifty-four weeks later these two muscles were contracting feebly. Successive examination up to 134 weeks after the injury indicated that no further motor recovery was to be expected. There was no improvement in cutaneous sensation. The end result was poor.

CASE 246.—N.D.S. was a repatriated prisoner of war. He sustained a mortar bomb wound of the right arm on May 31, 1941; this resulted in a fracture of the middle third of the shaft of the humerus. The following scars were present: (*a*) a large, depressed, irregular scar on the postero-medial aspect of the arm centred 16·5 centimetres above the medial epicondyle; (*b*) a vertical linear scar, 4·0 centimetres long, extending proximally along the inner margin of the biceps from a point 7·5 centimetres above the cubital crease; (*c*) a small oval scar superficial to the radial nerve and centred 4·0 centimetres above the cubital crease.

Prisoner-of-war notes state that there were complete radial and ulnar nerve lesions and that the wounds discharged for four months and required numerous operations for the removal of sequestra. When the patient was first examined by me, 138 weeks after the injury, the residual disability in the radial field was confined to a marked paresis of the movements of extension and radial abduction of the thumb. The posterior cutaneous nerve of the forearm had apparently not been involved. The only conducting fibres in the ulnar nerve were those supplying the *flexor carpi ulnaris* and ulnar half of *flexor digitorum profundus*. Motor function (radial nerve) was fully restored at 154 weeks, at which time the residual motor disability was attributable to the ulnar nerve lesion. At 290 weeks there had been no improvement of cutaneous sensation. There was no extraneural disability. The end result was complete restoration of function.

CASE 258.—R.W.W. sustained multiple perforating bullet wounds of the right arm on November 19, 1943; these resulted in a fracture of the humerus at the junction of the middle and upper thirds of the shaft. The radial nerve was involved in a wound which was marked by a large, depressed, oval scar, 7·0 by 2·5 centimetres, 5·0 centimetres above the lateral epicondyle. There was a complete lesion involving the brachioradialis; the posterior cutaneous nerve of the forearm was independently involved. The wounds were infected and considerable residual scarring took place above the lateral epicondyle.

Contraction was observed first in the brachioradialis at 18 weeks and last in the *extensor pollicis longus* at 37 weeks. When the patient was last examined at 121 weeks all movements were fully and strongly executed. There was good synergic extension of the wrist and the power of the grip equalled that on the opposite side. Cutaneous sensation in the field of the posterior cutaneous nerve of the forearm commenced to improve at 23 weeks, and at 121 weeks the band of disturbed sensation had been reduced to 1·0 centimetre in width. There had been some improvement, together with a reduction of the affected area, in the field of the superficial radial nerve. There was no residual extraneural disability. The end result was complete restoration of function.

CASE 276.—S.H. was a repatriated prisoner of war. He sustained a gunshot wound of the left arm on April 22, 1941; this resulted in a comminuted fracture of the middle third of the shaft of the humerus. The following scars were present: (*a*) a large deep scar, 11·5 centimetres long, extending upwards along the outer aspect of the arm from a point 9·0 centimetres above the lateral epicondyle; (*b*) a linear scar, 5·0 centimetres long, slightly oblique, commencing 6·5 centimetres above the medial epicondyle and extending upwards along the postero-medial aspect of the arm. Prolonged infection had taken place with considerable residual scarring. Prisoner-of-war notes reported a complete lesion of the radial nerve and a partial lesion of the ulnar nerve. When the patient was first examined by me at 151 weeks all muscles supplied by the radial nerve were functioning normally, while there was a residual paresis in the ulnar-supplied intrinsic muscles. The range of all movements of the wrist and hand was considerably reduced owing to extraneural changes. The posterior cutaneous nerve of the forearm had apparently not been involved. When the patient was last examined at 257 weeks sensation in the field of the superficial radial nerve had improved but slightly. The end result was complete restoration of function.

CASE 286.—E.J.O'L. sustained perforating bullet wounds through the right shoulder and upper third of the arm on December 10, 1943, with complete shattering of the upper four inches of the shaft of the humerus. The point of entry was marked by a large depressed scar at the outer end of the clavicle; the point of exit by a large, irregular, depressed scar, 10·0 by 5·0 centimetres, on the dorsum of the arm just lateral to the posterior axillary fold. Extensive soft tissue destruction took place; severe infection and considerable residual scarring followed. There was a complete lesion of the radial nerve involving the brachioradialis and posterior cutaneous nerve of the forearm. When the patient was first examined by me at 23 weeks the triceps and brachioradialis were contracting strongly. The remaining muscles were paralysed. The *extensor carpi radialis* commenced to contract at 28 weeks and the *extensor carpi ulnaris* at 37 weeks. At 55 weeks the brachioradialis and wrist extensors were

contracting powerfully, but no other muscles had recovered. There had been no improvement in cutaneous sensation. In view of the extensive scarring and the excellent function in the triceps, brachioradialis and the wrist extensors, it was decided not to explore the nerve but to resort to tendon transplantations to compensate for the residual motor disability. Residual extraneural changes considerably impaired all movements of the forearm, wrist and fingers. The appropriate transplantations were carried out at 114 weeks. The end result was poor.

CASE 310.—E.R.A. sustained a shrapnel wound of the middle and lower thirds of the right arm on April 4, 1944; this resulted in a comminuted fracture at the junction of the middle and lower thirds of the shaft of the numerus. A large oblique scar, 13·0 by 6·0 centimetres, occupied the lateral aspect of the cubital fossa and extended above the lateral epicondyle. There was extensive damage to the triceps, brachioradialis, *extensor carpi radialis longus* and lateral portion of the brachialis with destruction of the lateral intermuscular septum. The radial nerve had been severed about one inch above the lateral epicondyle, and the "grossly contused" nerve ends had been sutured loosely with black silk. Prolonged and severe infection took place. Soft tissue loss followed with considerable residual scarring.

The nerve was explored 193 days later and a 7·5 centimetre gap was found between the nerve ends. Segments of the median and ulnar nerves taken from an arm which had been amputated the previous day were inserted as a graft. When the patient was last examined, 52 weeks after the grafting, there was no evidence of recovery. The end result was no recovery.

## INCIDENCE AND DISTRIBUTION OF THE LESIONS.

*General.*—Single lesions were almost three times as numerous as combined lesions; in the latter the ulnar nerve was more commonly involved than the median. There was a slightly higher incidence on the right side. Lesions due to gunshot injuries comprised two-thirds of the cases. With 52% of all lesions there was an associated bone injury.

*Gunshot Lesions.*—Single lesions were almost three times as numerous as combined lesions, though each occurred with equal frequency on the two sides. Fracture of the humerus occurred in two-thirds of the single and three-quarters of the combined lesions. Thus the total number of cases associated with a fracture of the humerus was more than double that in which there was no bone injury.

Gunshot wounds and fractured humerus .. 15 (right), 14 (left).
Gunshot wounds without bone injury .. .. 7 (right), 7 (left).

*Lesions Due to Other Causes.*—Single lesions were three times as numerous as combined lesions. There was a higher incidence on the right both for single and combined lesions. The number of simple compression lesions was twice that due to penetrating injuries and simple fractures, which occurred in about equal proportions.

*Level of the Lesion.*—The distribution of the lesions with reference to the upper, middle and lower thirds of the arm was as shown in Table I.

TABLE I.

| Lesion. | Site in the Arm. | | |
|---|---|---|---|
| | Upper Third. | Middle Third. | Lower Third. |
| Laceration .. .. .. .. | 0 | 2 | 3 |
| Simple fracture .. .. .. .. | 1 | 4 | 0 |
| Gunshot wound .. .. .. .. | 2 | 4 | 8 |
| Gunshot wound with bone injury .. | 5 | 13 | 11 |
| Total .. .. .. .. | 8 | 23 | 22 |

Lesions due to gunshot and other penetrating injuries (not associated with bone injury) predominated in the lower third of the arm. The highest incidence of fractures was in the middle third of the arm where the nerve is particularly liable to damage owing to its intimate relation to bone.

## THE NATURE OF THE LESIONS.

### *Observed Pathological State.*

In 31 cases the nerve was not seen. In the remainder the condition of the nerve was reported in the battle notes or at subsequent exploration as follows:

(i) Severed: Cases 39, 40, 140, 180, 205, 225, 248, 282, 310.

(ii) Irreparably damaged (in continuity with intraneural and extraneural fibrosis): Cases 128, 134, 151, 170, 221, 243.

(iii) Damaged but recovered: Cases 27, 65, 203, 244.

(iv) Normal in appearance: Cases 202, 214, 231.

### *Deduced Pathological State.*

The nature of the nerve injury has been assessed, in terms of Seddon's classification (1942, 1943), on the basis of the course of regeneration.

The course of regeneration in Cases 214, 232 and 234 resembled that following simple compression injuries of the radial nerve (Sunderland, 1945) in that muscles innervated at different distances from the site of injury recovered simultaneously. The accumulated evidence, both clinical and experimental, suggests that the pathological changes due to compression, which interrupts conduction, must differ from those which follow a breach of continuity of the nerve. These changes are reversible and apparently do not involve Wallerian degeneration. But four points suggest that the changes in these three cases were more profound.

1. The Quiescent Period.—The quiescent period was longer than in any due to simple compression. The present observations suggest that a nerve may cease to conduct for 63 days and yet reawaken to activity without undergoing degeneration.

2. Sensation.—Sensation in the field of the superficial radial nerve remained defective for 60, 89, and 45 weeks respectively, which greatly exceeded the time required for the complete restoration of motor function. In simple compression injuries, on the other hand, cutaneous sensation is usually not affected and, when sensory defects do appear, the presence of a more profound lesion is suggested by the considerable delay in the restoration of motor function (Sunderland, 1945). The present findings confirm this.

3. Wasting.—Estimation of wasting was not relevant in Cases 232 and 234, owing to the presence of an associated median nerve lesion. In Case 214 considerable wasting persisted for 60 weeks after the injury, when it was present to the extent of 1·1 centimetres above and 2·0 centimetres below the lateral epicondyle. In no case of simple compression did wasting persist for this length of time.

4. Recovery of Power.—The slow recovery of power was a feature. In Case 232 motor function was fully restored at 31 weeks and at 32 weeks in Case 234 (both were complicated by median lesions). In Case 214 the average dynamometer readings for the grip 60 weeks after the injury were: right 270 and left 330 (patient right-handed). Rapid restoration to full power was, on the other hand, a feature of simple compression lesions.

The persistence of weakness, wasting and sensory defects indicated an intraneural disturbance sufficient to cause peripheral degeneration followed

by delayed or incomplete regeneration, while the course of the regeneration indicated that there had been little, if any, disturbance of the intraneural funicular pattern. These are features of the type of injury referred to by Seddon (1942, 1943) as axonotmesis.

On the other hand certain features suggest the condition which Seddon calls neurapraxia: (i) the recovery of muscles either simultaneously or after brief periods of delay not proportionate to the extra distances which regenerating axones would have to travel; (ii) recovery in distant muscles so early that it could not possibly be due to the growth of axones at anything approaching the estimated rates. However, the extended delay (up to 63 days) in the onset of motor recovery in cases which otherwise conform to the neurapraxic group is an unusual feature and if they are to be included the definition of the latter should be extended to include delayed motor recovery.

It would thus appear that in Cases 214, 232 and 234, while some of the fibres degenerated, the greater number to every muscle suffered a prolonged axoplasmic disturbance which did not lead to peripheral degeneration. The course of regeneration in Cases 81 and 117 suggests a similar injury.

A study of the rate and order of motor recovery in conjunction with the level of the lesion in Cases 27, 114, 202 and 244 indicated that the injury was not uniform throughout the nerve, the fibres to some muscles being more severely injured than those to others. The early or simultaneous recovery of some muscles suggested neurapraxia, while the more delayed and more orderly recovery in others indicated the intrafunicular interruption of fibres which has been termed axonotmesis. In Case 27 some fibres were observed at operation to have been severed (neurotmesis).

In Cases 69 and 99 it appeared that all the fibres had undergone Wallerian degeneration, though the severity of the injury had not been uniform, since some fibres preceded others in the regenerative process.

In Cases 7, 100, 106, 161, 185, 203, 231, 255, 258, 264 and 317 all the features were characteristic of axonotmesis. Though the severity of the lesions varied from case to case, the evidence indicated that all the fibres in each individual case had suffered the same degree of damage which resulted in peripheral degeneration followed by spontaneous reinnervation of the distal segment. The subsequent analyses relating to axonotmesis have been based on these cases. Though full details of the course of motor regeneration were not available in Cases 79, 97, 118 and 195, there was sufficient information to justify the inclusion of these cases in this group. Lack of detailed information in Cases 15, 18, 59, 64, 72, 99, 107, 246 and 276 prevented an accurate assessment of the nature of the lesion, but from the data available they also may be regarded as examples of axonotmesis.

The clinical features of Cases 65, 175 and 286 indicated that the fibres were not uniformly damaged; the full recovery of certain muscles was consistent with axonotmesis, while persistent paresis or paralysis (disregarding irreversible changes in the muscles) in others was proof of a lesion of the type defined as neurotmesis.

In Cases 65, 202, 203 and 244 the appearance of the nerve at the time of injury was a fairly reliable guide to the probable duration of the regenerative process, though it is not necessarily an accurate guide to the condition of individual fibres, since examples of neurapraxia occur in apparently severe injuries and examples of axonotmesis in nerves which appear to be normal.

The distribution of the lesions in terms of Seddon's classification is shown in Table II. From this it will be seen that the most serious lesions occurred in the gunshot injuries with fracture of the humerus.

TABLE II.

*The Distribution of the Lesions (Seddon's Classification).*

| Nature of Injury. | Neurapraxia. | Axonotmesis. | Neurotmesis. | Combined Neurapraxia and Axonotmesis. | Combined Axonotmesis and Neurotmesis. | Probable Axonotmesis. | Combined Neurapraxia, Axonotmesis and Neurotmesis. |
|---|---|---|---|---|---|---|---|
| Simple compression .. .. | 7 | — | — | 3 | — | — | — |
| Simple fracture .. | — | 3 | — | 1 | 1 | — | — |
| Laceration .. .. | — | 1 | 4 | — | — | — | — |
| Gunshot wound .. | — | 7 | 2 | 3 | — | 1 | 1 |
| Gunshot wound *plus* bone injury .. | — | 6 | 9 | 4 | 2 | 8 | — |
| Total .. | 7 | 17 | 15 | 11 | 3 | 9 | 1 |

## THE SEVERITY OF THE NERVE LESION AND ITS RELATION TO THE CAUSATIVE INJURY.

An attempt has been made to estimate the severity of the lesion on the basis of the duration of the interval between the receipt of the injury and the entry of regenerating axones into the distal segment. This interval has been called the initial delay and can be calculated from a knowledge of: (*a*) The latent period, that is, the time intervening between injury and the first signs of recovery. (*b*) The time taken by the regenerating axones to advance from the site of injury to the first muscle to recover. This can be calculated from the estimated rate of regeneration and from the distance which the fibres have to travel. (*c*) The time taken for the completion of those intramuscular changes upon which the restoration of voluntary contraction depends. Since there was no way of measuring this delay, it has been included with that occurring at the site of injury before the entry of axones into the distal segment. For this reason it should be understood that subsequent references to the initial delay carry the implication that this interval also includes the delay within the muscle.

*Rate of Regeneration.*—Regeneration rates have been calculated for the proximal and distal segments of the nerve below the origin of the branch to the brachioradialis (Sunderland, 1946). (See Table III.)

TABLE III.

| Condition. | Mean Rate of Regeneration in Millimetres per Day. | |
|---|---|---|
| | Proximal Segment. | Distal Segment. |
| Axonotmesis .. .. .. | 1·9 | 0·8 |
| Suture .. .. .. .. | 1·2 | 0·6 |

These results indicate that the rate diminishes as regeneration proceeds, so that growth is probably more rapid at higher levels than at those for which the rate of 1·9 was obtained—probably of the order of 3·0 millimetres per day, as suggested by Seddon, Medawar and Smith (1943). Since the rate for the portion of the nerve above the brachioradialis could not be calculated by the method employed, and in the absence of a large number of sutures

from which to obtain a more precise average rate for that group, the rate of 1·9 millimetres per day was employed in all calculations.

*The Distance from the Site of the Injury to the First Muscle to Recover.*—The average shortest and longest distances to the individual muscles along the radial nerve from a point 10·0 centimetres above the lateral epicondyle, together with their range of variation, have been measured in 20 dissected specimens (Sunderland, 1946). The shortest distances are given in Table IV.

TABLE IV.

*Shortest Distances (in Millimetres) to Muscles Supplied by the Radial Nerve. These Measurements were Employed in Calculating the Initial Delay.*

| | Measurements taken from a Point 10·0 Centimetres above the Lateral Epicondyle. | | Measurements taken from the Lateral Epicondyle. | | | |
|---|---|---|---|---|---|---|
| | B.R. | E.C.R.L. | E.C.U. | E.D.C. | A.P.L. | E.P.L. |
| Mean .. .. | 82 | 105 | 102 | 102 | 114 | 139 |
| Standard deviation .. | 15 | 11 | 20 | 21 | 21 | 23 |

[1] In this table B.R. incidates brachioradialis; E.C.R.L., *extensor carpi radialis longus*; E.C.U., *extensor carpi ulnaris*; E.D.C., *extensor digitorum communis*; A.P.L., *abductor pollicis longus*; and E.P.L., *extensor pollicis longus*.

If the distance from the lesion to the lateral epicondyle is known, the distance from the lesion to the muscles can be calculated.

### *The Initial Delay Following Axonotmesis.*

Values for the initial delay in twelve cases of axonotmesis are given in Table V. In general, the variations in the initial delay (6·3 to 32 weeks) may be accepted as an expression of the relative severity of the injury in each case. As a rule the delay was longer in lesions due to gunshot injuries, particularly if associated with compound fractures of the humerus and considerable infection

TABLE V.

| Nature of Injury. | Level of Injury in Centimetres. | Infection. | Scar. | Initial Delay in Weeks. | First Contraction in Weeks. | Last Contraction in Weeks. | Difference. |
|---|---|---|---|---|---|---|---|
| *Axonotmesis.* | | | | | | | |
| Simple fracture. | | | | | | | |
| Case 77 .. | 10·0 | Nil | Nil | 9·8 | 16 | 27 | 11 |
| Case 161 .. | 10·0 | Nil | Nil | 6·8 | 13 | 28 | 15 |
| Case 317 .. | 10·0 | Nil | Nil | 9·8 | 16 | 29 | 13 |
| Gunshot wound. | | | | | | | |
| Case 185 .. | 12·0 | Nil | Nil | 6·3 | 14 | 30 | 16 |
| Case 203 .. | 9·0 | Nil | Nil | 14·6 | 20 | 31 | 11 |
| Case 255 .. | 2·0 | I | S | 8·0— | 8 | 26 | 18 |
| Case 264 .. | 1·0 | Nil | S | 12·9 | 14 | 34 | 20 |
| Gunshot wound *plus* fracture. | | | | | | | |
| Case 231 .. | 12·5 | I | S | 32·0 | 40 | 56 | 16 |
| Case 118 .. | 9·0 | I | S | 10·6 | 16 | 28 | 12 |
| Case 100 .. | 7·5 | I | S | 17·0 | 23 | 32–36 | 9–13 |
| Case 106 .. | 5·0 | I | S | 14·6 | 17 | 36 | 19 |
| Case 258 .. | 5·0 | I | S | 15·6 | 18 | 37 | 19 |
| *Suture.* | | | | | | | |
| Laceration. | | | | | | | |
| Case 282 .. | 12·5 | Nil | Nil | 14·0 | 22 | 45 | 23 |
| Case 180 .. | 4·0 | Nil | S | 16·6 | 20 | 42 | 22 |
| Gunshot wound. | | | | | | | |
| Case 40 .. | 5·0 | I | S | 15·9 | 20 | 40 | 20 |

I and S=significant infection and scarring, respectively.

and scarring. Cases 118, 185 and 255, however, were exceptions. The level of the lesion appears to have no effect on the duration of the initial delay.

### *The Initial Delay following Suture.*

The period of delay varied between 14 and 16·6 weeks (Table V). The shorter interval (14 weeks) in Case 282 can be attributed to the absence of infection and early suture. In Case 180 the nerve was sutured 38 days after the injury, and though the wound was not infected the residual scarring was considerable. In Case 40 there was considerable early wound infection and scarring, while secondary suture was not performed until eleven months after injury. However, considering the adverse features of Cases 40 and 180, the differences in the initial delay are remarkably small. A possible explanation of this is that a well-executed suture converts the lesion in each case to one of equivalent severity. It should be noted that in Case 40 a delay of eleven months before suture did not materially influence either the initial delay or the course of regeneration.

### *Discussion.*

The initial delay may be accepted as a measure of the severity of the nerve injury. In establishing this relationship the findings in the simple fracture and suture groups were of particular significance.

In the three cases of simple fracture the initial delay was approximately 7, 10 and 10 weeks. In all three the initial violence and the course of regeneration were similar, infection and scarring were absent and the X-ray and clinical findings indicated that the nerve was damaged at the same level. From these findings it may be concluded that the extent of the lesion was similar in each case and minimal in degree. In the suture group the initial delays were 14, 15·9 and 16·6 weeks.

The regeneration in Case 118 (gunshot wound with significant infection and scarring) closely resembled that observed in the simple fracture group; apparently the damage to the nerve was not severe and infection and local scarring had not delayed regeneration. On the other hand, in Cases 203 (gunshot wound), 100, 106 and 258 (gunshot wound plus fracture) the initial delay approximated to that following suture, which indicated that the injury to the nerve in these cases was more severe than in the simple fracture group. The maximum initial delay was 32 weeks and occurred in a case of axonotmesis (Case 231, gunshot wound plus fracture).

Between these extremes will be found all intervening grades of severity of injury which will account for variations in the initial delay. Thus in cases of axonotmesis the severer the injury, the closer will the course of regeneration approximate to the sequence of events following suture. According to Seddon, Medawar and Smith (1943) "there is no doubt whatever that the latent period after suture is longer than that after axonotmesis". In general, the present findings confirm their observation, but information provided in Table V indicates that this is not invariably the case.

## THE COURSE OF RECOVERY.

### *Motor.*

Motor recovery may be divided into three stages:

(i) The recovery of tone and voluntary contraction. The order in which the muscles recovered and the duration of paralysis for each are shown in Table VI.

TABLE VI.

*Return of Voluntary Contraction in the Muscles Supplied by the Radial Nerve. The Cases have been Grouped According to the Causative Injury and the Level of the Lesion.*

| Case. | Causative Injury. | Approximate Level of Injury above Epicondyle. | Infect.[1] | Scar.[1] | Return of Voluntary Contraction in Weeks.[2] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | B.R. | E.C.R.L. | E.D.C. | E.C.U. | A.P.L. | E.P.L. |
| 65 | Simple fracture. | 24·0 centimetres. | Nil | Nil | 37–64 | 37–64 | 37–64 | 37–64 | 37–64 | 37–64 |
| 77 | Simple fracture. | 10·0 centimetres. | Nil | Nil | 16 | 18 | 23 | 23 | 25 | 27 |
| 161 | Simple fracture. | 10·0 centimetres. | Nil | Nil | 13 | 14 | 21 | 23 | 25 | 28 |
| 232 | Simple fracture. | 10·0 centimetres. | Nil | Nil | 9 | 8½ | 8½ | 8½ | 9 | 9 |
| 317 | Simple fracture. | 10·0 centimetres. | Nil | Nil | 16 | 18 | 24 | 22 | 25 | 29 |
| 195 | Laceration. | 15·0 centimetres. | Nil | Nil | 11–14 | 11–14 | 18 | 19–23 | 19–23 | 19–23 |
| 114 | Gunshot wound. | 24·0 centimetres. | I | Nil | 16 | 9 | 19 | 19 | 27 | 28 |
| 244 | Gunshot wound. | 15·0 centimetres. | Nil | Nil | 6 | 6 | 28 | 28 | 29–46 | 29–46 |
| 27 | Gunshot wound. | 12·5 centimetres. | Nil | Nil | Intact[3] | 3 | 13 | 19 | 13 | 21 |
| 185 | Gunshot wound. | 12·0 centimetres. | Nil | Nil | 14 | 16 | 22 | 24 | 26 | 30 |
| 64 | Gunshot wound. | 11·0 centimetres. | Nil | Nil | 22–29 | 22 | 22–29 | 22–29 | 22–29 | 22–29 |
| 70 | Gunshot wound. | 10·0 centimetres. | Nil | Nil | 4–18 | 4–18 | 21 | 26 | 28–30 | 28–30 |
| 203 | Gunshot wound. | 9·0 centimetres. | Nil | Nil | 20 | 20 | 27 | 27 | 31 | 31 |
| 255 | Gunshot wound. | 2·0 centimetres. | I | S | 8 | 8 | 18 | 18 | 20 | 26 |
| 264 | Gunshot wound. | 1·0 centimetres. | Nil | S | Intact | 14 | 23 | 23 | 25 | 34 |
| 69 | Gunshot wound. | Furrow. | I | S | Intact | 14–20 | 13 | 14–20 | 14–20 | 25 |
| 97 | Gunshot wound. | Furrow. | I | S | Intact | 12 | 22 | 17 | 22–58 | 22–58 |
| 202 | Gunshot wound. | Furrow. | I | S | 14 | 14 | 8 | 14 | 10 | 10 |
| 59 | Gunshot wound *plus* bone injury. | 21·0 centimetres. | Nil | Nil | 9–63 | 9–16 | 9–63 | 9–63 | 9–63 | 9–63 |
| 99 | Gunshot wound *plus* bone injury. | 20·0 centimetres. | I | S | 26–28 | 24 | 26–28 | 26–28 | 26–28 | 33 |
| 286 | Gunshot wound *plus* bone injury. | Upper third. | I | S | 1–23 | 28 | — | 37 | — | — |
| 18 | Gunshot wound *plus* bone injury. | 19·0 centimetres. | I | S | 51–76 | 23–30 | 23–30 | 23–30 | 23–30 | 23–30 |
| 214 | Gunshot wound *plus* bone injury. | 15·0 centimetres. | I | S | 3 | 3 | 5 | 5 | 6 | 6 |
| 81 | Gunshot wound *plus* bone injury. | Middle third. | Nil | Nil | 7–19 | 7–19 | 7–19 | 7–19 | 7–19 | 7–19 |
| 231 | Gunshot wound *plus* bone injury. | 12·5 centimetres. | I | S | 40 | 42 | 50 | 45 | 50 | 56 |
| 234 | Gunshot wound *plus* bone injury. | 12·5 centimetres. | Nil | Nil | 6 | 6 | 10–14 | 10–14 | 10–14 | 10–14 |
| 72 | Gunshot wound *plus* bone injury. | 11·0 centimetres. | Nil | Nil | 1–15 | 20 | 20–30 | 20–30 | 20–30 | 20–30 |
| 118 | Gunshot wound *plus* bone injury. | 9·0 centimetres. | I | S | 16 | 17–20 | 17–20 | 17–20 | 28 | 28 |
| 117 | Gunshot wound *plus* bone injury. | 7·5 centimetres. | I | S | 1–9 | 1–9 | 1–9 | 1–9 | 1–9 | 1–9 |
| 100 | Gunshot wound *plus* bone injury. | 7·5 centimetres. | I | S | Intact | 23 | 28–31 | 28–31 | 32–36 | 32–36 |
| 15 | Gunshot wound *plus* bone injury. | 6·0 centimetres. | I | S | 1–31 | 1–31 | 1–31 | 1–31 | 1–31 | 1–31 |
| 106 | Gunshot wound *plus* bone injury. | 5·0 centimetres. | I | S | 17 | 20 | 27 | 30 | 31 | 36 |
| 258 | Gunshot wound *plus* bone injury. | 5·0 centimetres. | I | S | 18 | 22 | 32 | 31 | 35 | 37 |
| 282 | Suture laceration. | 12·5 centimetres. | Nil | Nil | 22 | 27 | 37 | 36 | 40 | 45 |
| 180 | Suture laceration. | 4·0 centimetres. | Nil | S | 28 | 20 | 31 | 31 | 34 | 42 |
| 225 | Suture laceration. | Furrow. | Nil | Nil | 19–121 | 19–121 | 19–121 | — | 19–121 | — |
| 40 | Suture gunshot wound. | 5·0 centimetres. | I | S | Intact | 20 | 34 | 35 | 40 | 40 |

[1] I and S indicate significant infection and scarring, respectively.

[2] In this table, B.R. indicates brachioradialis; E.C.R.L., *extensor carpi radialis longus*; E.D.C., *extensor digitorum communis*; E.C.U., *extensor carpi ulnaris*; A.P.L., *abductor pollicis longus*; and E.P.L., *extensor pollicis longus*.

[3] The muscle was originally paralysed but was contracting when I first examined it.

(ii) The recovery of full power and the capacity to perform a full range of voluntary movement. This is a gradual process which, in the mildest cases, requires about 36 to 60 weeks and in the severer injuries up to three years for the full restoration of power.

(iii) Recovery of the ability to participate in complex motor patterns such as synergic extension at the wrist when making a grip. This, the last component of muscle function to be restored, does not appear until stage 2 is well advanced and in any residual defect is the most seriously affected.

### *Sensation.*

*Posterior Cutaneous Nerve of the Forearm.*—When the posterior cutaneous nerve of the forearm was injured the area of impaired sensation

consisted of a band of varying width extending along the dorsum of the forearm from the lateral epicondyle to the wrist.

The posterior cutaneous branch frequently leaves the radial nerve in the brachio-axillary angle and accompanies it into the groove, where the nerve is usually applied to bone while the cutaneous branch is as a rule located more posteriorly between the heads of the triceps. This arrangement renders the radial more liable to injury in fractures of the middle third of the humerus. Occasionally, however, the cutaneous nerve does not branch until the radial nerve has descended some distance along the groove. Its involvement therefore depends not only on the level of the injury, but also on the site of the branching from the radial nerve.

Sensation in the field of this branch was normal when patients 59, 175, 246 and 276 were first examined 63, 63, 138 and 151 weeks respectively after the injury; their previous records contained no reference to the state of sensation over the dorsum of the forearm. The state of sensation in the remaining patients is shown in Table VII, where the lesions have been grouped in terms of the level and nature of the causative injury.

TABLE VII.

*Involvement of the Posterior Cutaneous Nerve of the Forearm.*

| Injury | Upper Third. | | Middle Third. | | Lower Third. | |
|---|---|---|---|---|---|---|
| | Intact. | Involved. | Intact. | Involved. | Intact. | Involved. |
| Simple fracture | | 65—some recovery. | 161, 232, 317 | 77—some recovery. | | |
| Laceration .. | | | | 195—full recovery.<br>282—some recovery. | 170 | 180 — no recovery. |
| Gunshot wound | | 248—no recovery.<br>114—good recovery. | 27, 64, 185, 244 | | 69, 79, 97, 203, 255, 264 | 40, 202—no recovery. |
| Gunshot wound *plus* bone injury. | 99 | 39, 286—no recovery.<br>209—end result unknown. | 81, 214 | 128, 134, 151, 221, 231, 234—no recovery.<br>18, 72 — some recovery. | 15, 107, 117, 118 | 140, 205, 243, 310—no recovery.<br>100—full recovery.<br>106, 258—some recovery. |
| Total .. | 1 | 6 | 9 | 11 | 11 | 10 |

These cutaneous fibres were involved in all but one of the upper third lesions, and this could be accounted for by the extensive character of the injuries and the disposition of the fibres at that level. Recovery was good in one case (114) and there was some improvement in another (65); in each case the sensory recovery was comparable with the motor recovery, indicating a similar degree of injury to both sets of fibres. There was no recovery in Cases 39, 248 and 286; this was consistent with the severity of the motor lesion. The preservation of sensation in Case 99 may have been due either to a high branching of the nerve, whose fibres thereby escaped injury, or to an abnormality in the cutaneous supply of the forearm.

In lesions of the middle third there was a high incidence of involvement in those due to gunshot wounds with a fracture of the humerus. Here the ratio of involvement to escape was 8 to 2 as against 1 to 3 in the simple fracture group; this was consistent with the violence of the injury in the

former. In Cases 128, 134, 151 and 221 the nerve was irreparably damaged in the groove, and the cutaneous fibres, whether running separately or contained within the nerve, suffered the same fate. In Cases 231 and 234 the advanced state of motor recovery, the absence of sensory improvement and the site of the wounds indicated that the cutaneous branch had been independently severed. The degree of sensory recovery in Case 195 was in keeping with the course of motor regeneration and suggested that the sensory fibres had suffered an injury similar to that sustained by the motor fibres. In Cases 18, 72 and 77 motor recovery was out of all proportion to the sensory recovery, and from this it may be assumed that the sensory fibres had suffered a severer and more permanent injury.

In lower third lesions involvement of the posterior cutaneous nerve indicated independent injury in the wound. When this occurred the damage was severe and in only three of the ten cases was any sensory recovery observed (full recovery in Case 100 and partial recovery in Cases 106 and 258).

*Superficial Radial Nerve.*—In Case 205, though the radial nerve was severed, there was no disturbance of cutaneous sensation in the hand. This indicated that the area usually innervated by this nerve was supplied from some other source. Appleton (1911) has described a specimen in which the cutaneous field of the superficial radial nerve, which was absent, was innervated by the musculo-cutaneous nerve.

In the remaining cases sensation was defective over an area which varied from patient to patient, but which in general covered that customarily attributed to this cutaneous nerve. In some patients sensation was uniformly diminished over the entire area, though the degree of loss varied from patient to patient. In others an area could be outlined within the involved field where the sensory impairment was greater.

*Sensory Recovery.*—Sensory recovery occurred in two phases. The first involved a reduction in the depth of the sensory defect and always preceded, but was not necessarily followed by the second, in which there was a gradual reduction of the involved area. This continued until the latter was either completely eliminated or reduced, in the case of the posterior cutaneous, to a narrow band along the dorsum of the forearm and, in the case of the superficial radial, to a circular area on the first web or a strip along the dorsum of the thumb.

The findings in the case of the superficial radial nerve were of particular interest. There was no recovery of sensation in the three sutured nerves (40, 180 and 282) in which satisfactory motor recovery occurred. In the remaining lesions, in which motor recovery was either complete or just short of it, sensation was fully restored or was advancing at a rate and in a manner to justify the expectation that it would be restored, in only seven (Cases 69, 72, 79, 81, 161, 185 and 195). In 15 cases some improvement was suggested by a reduction in the extent or in the depth of the defect or in both (Cases 27, 59, 65, 99, 100, 106, 114, 117, 203, 214, 244, 255, 258, 264 and 317) and by either no or insignificant sensory recovery in 12 (Cases 15, 18, 64, 77, 107, 118, 202, 231, 232, 234, 246 and 276).

A striking feature was the persistence of the sensory defect in lesions in which motor recovery was fully and rapidly restored and in which everything pointed to an injury of minimal degree. Furthermore, sensory recovery occurred in some cases in which the progress of motor regeneration did not appear to differ from others in which there was no sensory recovery. The implications of these observations do not fall within the province of this report and will be discussed in detail elsewhere.

*Wasting.*

The data relating to wasting were incomplete and only certain generalizations appear to be justified. A representative series of measurements is given in Table VIII, and, since these provide a cross-section of the entire series, it is unnecessary to include the figures for every patient.

Though it could not be ascertained when wasting first appeared, it was usually well advanced by the fifth week and, when recovery occurred spontaneously, appeared to reach a peak 9 to 24 weeks after interruption of conduction. Normally it was gradually reduced with the reappearance of voluntary movements, though it frequently persisted for considerable periods after power had been fully restored. In the irreparable lesions the wasting continued and ultimately reached values ranging from 4·6 to 5·6 centimetres.

A relationship appeared to exist between the degree of the wasting and the severity of the extraneural injury which determined the period of immobilization and therefore the influence of disuse. In general, the wasting was greater and persisted for a longer period and in greater degree in the gunshot wound *plus* bone injury group, where the limb was immobilized for long periods.

## INFLUENCE OF THE DURATION OF THE LATENT PERIOD ON THE SUBSEQUENT COURSE OF REGENERATION.

The course of regeneration subsequent to the onset of recovery may be expressed in terms of the time taken to reinnervate the entire pattern which is the interval between the first appearance of recovery and the appearance of contraction in the last muscle to recover. This period varied between 11 and 23 weeks. It was minimal in the simple fracture group and maximal in the suture group.

There are four possible explanations of the observed differences in the time taken to reinnervate the pattern.

1. The linear extent of the pattern varies over wide limits in different individuals. The recorded differences are of such a magnitude that they alone could account for the variations in time.

2. The rate of regeneration may vary in different individuals. It is unlikely that the rate is constant, though the possible range of variation is unknown. It is improbable, however, that this factor alone would account for the differences in the time taken to reinnervate the pattern.

3. Some nerve fibres may be more severely damaged than others, and this may introduce a variation in the initial delay for different fibres. That this may occur has been deduced from the sequence of events following the injury in Cases 27, 69, 99, 114, 202 and 244. To explain the variations in the time taken to reinnervate the entire pattern on this basis, the onset of regeneration in the fibres destined for either the first or last muscle to recover, or both, must be delayed, though not in such a way as to disturb the normal serial order of recovery.

4. It may be that the overall rate of regeneration is slower in cases in which the initial delay is longer, that is, in cases in which the injury has been more severe but in which all the fibres have been uniformly affected.

If the duration of the initial delay is any guide to the severity of the injury, and there is some evidence to indicate that it is, then it might be expected that initial delays of long duration would be associated with the longer periods taken to reinnervate the pattern. Reference to Table V will show that in general this is so, particularly in the suture group in which the injury is maximal in degree.

TABLE VIII.

*Wasting Correlated with the Onset of Contraction in the First and Last Muscles to Recover and with the Power of the Grip as Registered by the Dynamometer.*

**All measurements were taken from a point 7·5 centimetres below the medial epicondyle.**

| Case and Nature of Injury. | Time of Examination in Weeks. | Right Arm. (Centimetres.) | Left Arm. (Centimetres.) | Wasting. (Centimetres.) | Onset of Motor Recovery in Weeks. | Last Muscle to Contract in Weeks. | Grip. | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Right. | Left. |
| Case 77. Simple fracture. | 14 | 29·8 | 26·6 | 3·2 | 16 | 27 | | |
| | 19 | 29·8 | 26·3 | 3·5 | | | | |
| | 23 | 29·8 | 27·2 | 2·6 | | | | |
| | 28 | 29·8 | 27·2 | 2·6 | | | | |
| | 34 | 29·2 | 26·6 | 2·6 | | | | |
| | 50 | 29·2 | 28·2 | 1·0 | | | | |
| Case 282. Laceration. | 9 | 24·2 | 26·0 | 1·8 | 22 | 45 | | |
| | 22 | 24·7 | 26·7 | 2·0 | | | 65 | 225 |
| | 45 | 25·5 | 26·6 | 1·1 | | | 80 | 230 |
| | 54 | 26·0 | 27·8 | 1·8 | | | 100 | 230 |
| | 63 | 26·4 | 27·5 | 1·1 | | | 140 | 230 |
| | 79 | 26·4 | 27·8 | 1·4 | | | 170 | 270 |
| | 91 | 27·0 | 28·0 | 1·0 | | | 160 | 260 |
| | 104 | 26·5 | 27·5 | 1·0 | | | 170 | 265 |
| Case 40. Gunshot wound. | 31 | 21·5 | 25·3 | 3·8 | 20 after suture | 40 after suture | | |
| | 40 | 25·7 | 21·9 | 3·8 | | | | |
| | 53 | 25·3 | 20·9 | 4·4 | | | | |
| | 135 | 23·1 | 25·0 | 1·9 | | | 118 | 295 |
| | 165 | 23·4 | 25·5 | 2·1 | | | 150 | 300 |
| Case 69. Gunshot wound. | 13 | 25·3 | 22·8 | 2·5 | 13 | 25 | | |
| | 21 | 26·6 | 24·7 | 1·9 | | | | |
| | 26 | 26·6 | 24·7 | 1·9 | | | | |
| | 31 | 26·6 | 26·0 | 0·6 | | | | |
| | 36 | 26·3 | 25·7 | 0·6 | | | | |
| Case 114. Gunshot wound. | 5 | 24·4 | 21·9 | 2·5 | 9 | 28 | | |
| | 9 | 24·4 | 21·5 | 2·9 | | | | |
| | 53 | 24·1 | 22·2 | 1·9 | | | 265 | 190 |
| | 72 | 25·3 | 23·7 | 1·6 | | | 280 | 215 |
| | 79 | 26·0 | 24·1 | 1·9 | | | 280 | 235 |
| | 88 | 26·0 | 24·1 | 1·9 | | | 280 | 230 |
| | 97 | 24·7 | 22·7 | 2·0 | | | 260 | 220 |
| | 106 | 25·0 | 23·2 | 1·8 | | | 280 | 275 |
| | 122 | 25·5 | 23·8 | 1·7 | | | 285 | 275 |
| | 131 | 25·6 | 24·0 | 1·6 | | | 280 | 270 |
| | 137 | 25·6 | 24·0 | 1·6 | | | 285 | 275 |
| | 141 | 25·8 | 24·3 | 1·5 | | | 280 | 260 |
| | 146 | 26·0 | 24·5 | 1·5 | | | 270 | 265 |
| Case 255. Gunshot wound. | 9 | 26·0 | 24·4 | 1·6 | 8 | 26 | | |
| | 26 | 27·5 | 26·0 | 1·5 | | | 220 | 110 |
| | 30 | 27·5 | 26·3 | 1·2 | | | 270 | 140 |
| | 33 | 27·3 | 26·2 | 1·1 | | | 265 | 160 |
| | 45 | 27·2 | 25·7 | 1·5 | | | 280 | 185 |
| | 51 | 27·0 | 25·7 | 1·3 | | | 260 | 180 |
| | 59 | 27·1 | 26·0 | 1·1 | | | 255 | 170 |
| | 74 | 27·7 | 26·7 | 1·0 | | | 260 | 180 |
| | 90 | 27·5 | 26·5 | 1·0 | | | 260 | 170 |
| | 102 | 27·8 | 26·8 | 1·0 | | | 225 | 175 |
| | 115 | 27·0 | 26·5 | 0·5 | | | 240 | 180 |
| Case 72. Gunshot wound *plus* bone injury. | 15 | 27·8 | 22·8 | 5·0 | 20 | 20 to 30 | | |
| | 20 | 27·9 | 24·1 | 3·8 | | | | |
| | 30 | 28·5 | 25·3 | 3·2 | | | | |
| | 35 | 29·2 | 26·0 | 3·2 | | | | |
| | 41 | 30·4 | 26·6 | 3·8 | | | | |
| Case 106. Gunshot wound *plus* bone injury. | 9 | 23·1 | 26·6 | 3·5 | 17 | 36 | | |
| | 14 | 23·4 | 26·6 | 3·2 | | | | |
| | 20 | 23·7 | 26·3 | 2·6 | | | | |
| | 52 | 25·3 | 26·3 | 1·0 | | | 120 | 280 |
| | 58 | 25·3 | 26·3 | 1·0 | | | 115 | 275 |
| | 100 | 24·3 | 25·6 | 1·3 | | | 150 | 280 |
| | 105 | 24·7 | 25·5 | 0·8 | | | 130 | 265 |
| | 116 | 25·9 | 26·3 | 0·4 | | | 160 | 280 |
| | 150 | 25·5 | 26·2 | 0·7 | | | 190 | 320 |
| | 190 | 26·1 | 26·5 | 0·4 | | | 200 | 300 |
| Case 258. Gunshot wound *plus* bone injury. | 29 | 24·0 | 27·0 | 3·0 | 18 | 37 | 65 | 220 |
| | 35 | 24·7 | 27·6 | 2·9 | | | 90 | 215 |
| | 42 | 24·3 | 26·5 | 2·2 | | | 100 | 230 |
| | 64 | 25·7 | 27·2 | 1·5 | | | 180 | 220 |
| | 87 | 25·5 | 27·0 | 1·5 | | | 165 | 210 |
| | 99 | 25·7 | 27·5 | 1·8 | | | 180 | 220 |
| | 121 | 25·8 | 27·5 | 1·7 | | | 210 | 220 |

There are cases, however, which demonstrate that an early or late onset of recovery is not invariably followed by an accelerated or retarded innervation of the pattern respectively such as might be expected had all the fibres been uniformly involved. If the severity of the injury alone were in question, this evidence would indicate an injury of varying severity in individual fibres or funiculi. The onset of regeneration, then, must have been unduly delayed in those fibres destined for either the first or last muscles to recover, or both, though without in any way disturbing the order of reinnervation (see "3" above).

The presence of so many variable factors makes it extremely difficult to assess the relative participation and contribution of each. Briefly, one or a combination of the following three factors may influence the reinnervation time: (*a*) the variation in the linear extent of the pattern; (*b*) variations in the severity of the injury with reference to the entire cross-sectional area of the nerve or to individual fibres or funiculi composing it; (*c*) variations in individual rates of regeneration.

## THE ASSOCIATED EXTRANEURAL DISTURBANCE.

Apart from the influence of soft tissue injury, the extraneural disability was always related to the duration of immobilization. It is not proposed to consider the direct influence of the nerve lesion on articular and periarticular structures which, from a control study of immobilized limbs without nerve injury, appeared to be negligible.

The adverse effects of prolonged immobilization on tissues are too well known to call for comment. When well advanced they are difficult to correct, and by their persistence can seriously impair the use of a limb in which nerve function has been fully restored. Under battle conditions the prevention of such complications may be unavoidable, but the neglect of physiotherapy at a later date can only result in irreversible changes. Physiotherapy should be instituted as soon as possible, and it may be required for very long periods. In these matters the cooperation of the patient is all important. An intelligent patient can soon acquire sufficient knowledge of the required treatment to limit the need for institutional supervision or make it wholly unnecessary.

## TREATMENT AND END RESULTS.

In general, patients with peripheral nerve injuries sustained in the early Middle East campaigns were repatriated as soon as possible to a base hospital in this country for treatment. The delay incurred in awaiting transport, together with the time taken on the voyage home, lengthened considerably the interval between the date of the injury and the time when the patient came under observation in Melbourne. The late onset of spontaneous regeneration, which proceeded in a large proportion of these patients to complete recovery, encouraged a conservative policy for the treatment in later cases. Thus nerves known to be severed were repaired, where possible, immediately local conditions became favourable, while partial or complete lesions in which the anatomical condition of the nerve was not known, were given every opportunity to recover spontaneously before recourse was had to exploration. In general, exploration was not contemplated within six months of the injury. Such a policy was supported by previous observations (Tinel, 1917; Benisty, 1918; Foerster, 1929) that the majority of nerve lesions recover spontaneously and show some signs of this within six months.

The treatment and end results have been summarized in Table IX and the percentages of spontaneous recovery, suture and irreparable damage in Table X.

TABLE IX.

*Treatment and End Results.*

| Injury. | Recovery Complete or Sufficiently Advanced to Contraindicate Exploration. Condition of the Nerve. | | | | | | Exploration of the Nerve. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Anatomical. | | | Physiological. | | | Condition of Nerve before Exploration. | | | | | |
| | | Observed in Continuity in Wound. | | | | | | | | | | | |
| | Number. | Traumatized. | Normal. | Not Seen. | Complete Lesion. | Partial Lesion. | Number. | Known to be Severed. | Not Known. | In Continuity. Neurolysis only. Recovery. | Sutured. | Grafted. | Irreparably Damaged. |
| Compression .. | 10 | | | 10 | 8 | 2 | | | | | | | |
| Simple fracture .. | 4 | | | 4 | 4 | | 1 | | | 1 | | | |
| Laceration .. | 1 | | | 1 | 1 | | 4 | 2 | 2 | | 3 | | 1 |
| Gunshot wound .. | 12 | 3 | 1 | 8 | 12 | | 2 | | 2 | | 2 | | |
| Gunshot wound *plus* bone injury (one not traced) .. | 18 | | | 18 | 16 | 2 | 10 | 2 | 8 | 1 | 2 | 2 | 5 |
| Total .. | 45 | 3 | 1 | 41 | 41 | 4 | 17 | 4 | 12 | 2 | 7 | 2 | 6 |

TABLE X.

*Percentage Incidence of Spontaneous Recovery (R.), Suture (S.) and Irreparable Damage (D.) in the Radial Nerve Lesions.*

| Injury. | R. | S. | D. |
|---|---|---|---|
| Simple compression .. .. | 16 | 0 | 0 |
| Simple fracture .. .. | 8 | 0 | 0 |
| Laceration .. .. .. | 2 | 5 | 2 |
| Gunshot wound .. .. | 19 | 3 | 0 |
| Gunshot wound *plus* bone injury .. .. .. | 31 | 3 | 11 |
| Total .. .. .. | 76 | 11 | 13 |

In forty-five patients the nerve recovered spontaneously without exploration. In two cases a severed nerve was sutured immediately after the injury. A further fifteen nerves were explored, and of these, two were in a state of continuity not requiring repair, five were sutured, two grafted and six subjected to tendon transplantations owing to irreparable damage to the nerve. The two grafted nerves and two of those sutured did not recover and ultimately required tendon transplantation. The end result in the case of the seventeen explored nerves was therefore: sutured with recovery, five (in one of these, Case 243, the recovery recorded at the last examination was of little value and it appeared that tendon transplantations would ultimately be required to improve function); in continuity with recovery, two; and irreparably damaged, ten. There was a high incidence of irreparable lesions due to gunshot wounds which resulted in a fracture of the humerus.

### *Discussion.*

The outstanding fact emerging from an analysis of the end results is that the majority of the injured nerves recovered spontaneously; from this it may be inferred that anatomical continuity is usually preserved. Such an observation, however, gains significance only when it is examined in relation to the severity of the injury and to the extent and quality of the recovery. The two last-mentioned support the belief that the injured nerves were in continuity. The following observations concerning the severity of the injury are of importance.

1. Of lesions which recovered spontaneously, 92% were complete. The incidence was probably higher, since the four lesions classed as partial could, on the basis of the entire regenerative process, quite conceivably have originally been complete, but in the absence of any reliable data relating to the original nature of the lesion and in the presence of some conduction at my first examination several weeks after the injury they were classed as partial.

2. As already stated, the latent period comprises the sum of the initial delay at the site of injury and the time taken by the axones to advance to the first muscle recovering. The level of the injury influences the second, but not necessarily the first. Though the lesions were situated at a variety of levels, the conditions were such that this factor was never of such a magnitude as to affect significantly the general thesis that the duration of the latent period could be accepted as an indication of the severity of the injury. Values for the latent period for complete lesions recovering spontaneously are provided in Table VI, but have been simplified where possible in Table XI.

TABLE XI.

*Duration of Complete Interruption of Conduction in Cases in which Spontaneous Recovery Occurred.*

| Months. | Number of Cases. |
|---|---|
| 0 to 2 .. .. .. | 7 |
| 2 to 4 .. .. .. | 11 |
| 4 to 6 .. .. .. | 7 |
| 6 to 9 .. .. .. | 1 |
| 9+ .. .. .. .. | 2 |

The conclusions which may be drawn from this data are that the injury was severe in a high proportion of the cases in which recovery was clinically complete and in which spontaneous recovery occurred, and that recovery may be delayed for considerable periods and still proceed to completion.

In three of these cases the injured nerve was observed to have been lacerated and was hæmorrhagic in appearance.

These observations have an intimate bearing on the treatment of traumatic injuries of peripheral nerves.

The policy of exploring injured nerves in which interruption of conduction is complete immediately local conditions become favourable has the following advantages.

1. By permitting early repair it may shorten the period of incapacity, while irreparable injuries may be appropriately treated without delay.

2. The experimental work of Holmes and Young (1942) suggests that the chances of nerve suture being successful diminish as the period of delay

increases beyond two months, and particularly when it exceeds five to six months, and that early suture is followed by more rapid recovery than late suture. This is attributed to irreversible changes occurring in the distal segment, end organs and extraneural tissues, which are prejudicial to regeneration and functional recovery. Further information, based on a study of human material, is required in order to confirm these experimental observations, but there is some clinical evidence to the effect that delays up to six months do not necessarily adversely affect the rate of recovery or the end result (confirmed by personal observations). The time element is only one of many variable factors affecting the restoration of function following suture, and further investigation is required to evaluate correctly the influence of this factor.

3. Exploration in skilled hands is considered a safe procedure. Even in skilled hands, however, there remains the danger, during resection of scar tissue, of damaging intact or regenerating fibres and of converting a lesion in continuity into one of complete anatomical division.

Of these advantages the first alone is sufficient to warrant early exploration of the nerve. The conservative policy adopted during the present inquiry was in the first place imposed quite fortuitously, and though it has been fully justified (*vide* this report and others to follow) the merits of early exploration must be admitted. A *sine qua non* of early exploration, however, should be that regardless of the pathological changes present, a nerve which is in continuity should not be disturbed, but should be given every opportunity to recover spontaneously.

The presence of a neuroma should not be regarded as a justification for resection and suture. In a study of the incidence of neuroma formation in the complete series of nerve injuries, of which the radial lesions form a group, it has been shown that the presence of a neuroma involving a nerve in continuity is not necessarily a bar to recovery of an order surpassing that resulting from suture. Furthermore, repair may be followed by the formation of a bulb resembling that originally present. Incidentally, the absence of a motor response to proximal stimulation at early exploration obviously has no significance.

Foerster (1929) has also observed that the macroscopic appearance of the injured section of a nerve is an unreliable guide to the possibilities of regeneration. In view of the delicacy of nerve tissue, the difficulty of its repair and the unpredictable results of nerve suture, it is better to err by closing the wound when suture is indicated than to perform resection and suture when the nerve would have recovered spontaneously. The great danger of early exploration is the destructive interference with nerves which would recover spontaneously. In the first Great War, Spielmeyer (1918) found, from the histological examination of material resected in the early stages, that nerves were being resected which would probably have recovered spontaneously if left alone. Unless great care is exercised in the treatment of the exposed nerve, this experience is likely to be repeated.

The results of this investigation lend emphasis to the belief that it is advisable to preserve the continuity of an explored nerve, regardless of its nature, until the nerve has been given an opportunity to recover spontaneously. Unless this is done, the policy of early exploration will inevitably result in an increase in unnecessary sutures. Furthermore, delays of six to nine months do not necessarily adversely affect the end results of suture (personal observations). When the results have proved unsatisfactory, other variable factors affecting the regenerative process could have been responsible. The

sacrifice involved by delaying suture is more than compensated by the great advantage to be gained by permitting and obtaining spontaneous recovery.

One further point calls for brief comment. Spontaneous recovery occurred in all of the closed injuries, and for this reason early exploration should not be undertaken in these cases.

### TO ESTIMATE WHEN RECOVERY SHOULD APPEAR.

Nerves which have been explored and treated conservatively and which do not subsequently show signs of spontaneous recovery require reexploration, resection and suture. From a study of the initial delay the rate of regeneration and the distances to muscles from a fixed point on the nerve it has been possible to estimate when recovery, spontaneous and following suture, should be expected.

*The Presumed Initial Delay.*—An initial delay of up to approximately ten weeks may be expected in injuries (axonotmesis) which are minimal in degree. If the lesion is more severe, as it is following suture or after severe gunshot wounds associated with a fracture of the humerus, infection and extensive scarring, then a delay of somewhere in the vicinity of four months may be expected in all but the exceptional cases. Seddon *et alii* (1943) estimated this period in their clinical material by extrapolation. Excluding the cases in which a negative reading was obtained, extrapolation gave the following values.

Following axonotmesis of the radial nerve: 25, 29, 69, 71, 103, 185 and 218 days, with an average of approximately 14 weeks.

Following suture of the radial nerve: 68, 80, 132, 135, 151, 155 days, with an average of approximately 17 weeks.

In a later section in their paper these writers gave "six or eight weeks for an unduly long latent period" in cases of radial axonotmesis. This inconsistency was not explained.

*The Time Taken for the Axones to Travel.*—When the level of the lesion is known, the time taken for the axones to travel from the site of the injury to the brachioradialis or *extensor carpi radialis longus* may be calculated at an average rate of 1·9 millimetres per day.

In general, for a lesion situated 10·0 centimetres above the epicondyle the onset of recovery in the brachioradialis should not be delayed beyond approximately four months after "simple" injuries and six months following severe injuries or nerve suture. Admittedly it is difficult to distinguish between simple and severe nerve lesions, since the nature and severity of the causative injury is by no means an invariable guide. However, as previously shown, lesions are as a rule more severe when due to gunshot injuries, where the wounds are infected, where there is considerable scarring, or where the humerus is fractured. The latent periods have been further simplified, where possible, in Table XI, and these indicate that a delay of six months would cover all but a few cases. The maximum latent period observed before spontaneous regeneration became evident and proceeded to completion was ten months, though such a delay must be unusual. In the majority of the cases spontaneous regeneration was well advanced at the end of six months and ultimately proceeded to complete restoration of function.

By the addition of 11 to 23 weeks, according to the type and severity of the nerve lesion, to the date of onset of recovery in the first muscle to recover, it is possible to calculate the approximate time when voluntary contraction may be expected in the last muscle to be reinnervated. This

time naturally has no reference to the full restoration of function, which is not attained until several months or even years later.

## SUMMARY.

1. The case histories, course of regeneration, end result and treatment have been recorded for 62 patients with radial nerve injuries who have been under continuous observation for periods ranging from two to four years. The examinations throughout have been conducted by the same observer.

2. In all cases conservative treatment was adopted (unless the nerve was known to be severed), which meant that exploration was not contemplated within six months.

3. The end results were: in 45 cases the injured nerve recovered spontaneously without exploration; in two cases a severed nerve was sutured immediately after the injury; a further 15 nerves were explored, and of these, two were in a state of continuity not requiring repair, five were sutured, two grafted and six subjected to tendon transplantations owing to irreparable damage to the nerve. The two grafted nerves and two of those sutured did not recover and ultimately required tendon transplantations.

4. The relative merits of early and late exploration of clinically complete lesions have been discussed. Evidence is presented which lends emphasis to the belief that the majority of injured nerves will recover spontaneously if treated conservatively, and that if early exploration is undertaken it is advisable to preserve the continuity of the nerve, regardless of the pathological changes present, until it has been given an opportunity to recover spontaneously. While early exploration, by permitting prompt suture, is of value in cases of complete severance of the nerve, it is urged strongly that nerves found in continuity should not be disturbed.

5. A delay of six months before suture is not necessarily prejudicial to the end result. The time element is only one of many variable factors affecting the restoration of function following suture, and further investigation is required to evaluate correctly the influence of this factor.

6. Attention is directed to the dangers of too-prolonged immobilization and the value of physiotherapy is stressed.

7. When axones have been interrupted, significance is attached to the initial delay, which has been defined as the time between the injury and the entry of the regenerating axones into that portion of the nerve distal to the site of injury. (For the purposes of the paper the time taken for the completion of those muscular changes upon which the restoration of voluntary contraction depends, has also been included.)

A method for calculating this delay has been described.

(*a*) The duration of the initial delay was a measure of the severity of the nerve lesion.

(*b*) The initial delay was related to the time taken by the regenerating axones to reinnervate the entire motor field subsequent to the onset of recovery. In general, long and short initial delays were associated with long and short periods of reinnervation respectively.

(*c*) An initial delay of up to ten weeks followed the mildest cases of "axonotmesis", which were usually due to the simplest types of injury, such as those associated with simple fractures of the humerus. More severe injuries, such as those due to gunshot wounds associated with fractures of the humerus, infection and extensive scarring, were followed by an initial delay of approximately four months. This was also the usual period of delay

following suture. It is, however, difficult to differentiate between simple and severe nerve lesions, since the nature and severity of the causative injury was not a reliable guide.

8. The maximal period intervening between the injury and the onset of spontaneous recovery (latent period), which proceeded to completion, was ten months. In the majority of nerves regenerating spontaneously, however, recovery had appeared by the end of six months.

9. The probable date of recovery (spontaneous or after suture) can be calculated from a knowledge of (i) the presumed initial delay, (ii) the level of the lesion, and (iii) the rate of regeneration. Information relating to these three factors has been provided.

10. The approximate time when voluntary contraction may be expected in the last muscle to be reinnervated may be calculated by adding 11 to 23 weeks, according to the type and severity of the nerve lesion, to the date of the onset of recovery in the first muscle to recover.

11. The regeneration of motor fibres was not always accompanied by a corresponding recovery of sensory function.

## ACKNOWLEDGEMENTS.

This work was carried out while I was acting as a consultant on peripheral nerve injuries at an Australian military hospital, and the facilities there afforded me by the service authorities are gratefully acknowledged. Particularly am I indebted to the Repatriation Commission (Victorian Division) for the cooperation of its members in permitting the establishment of a follow-up clinic, which presented a unique opportunity for maintaining continuous records. The explorations were performed by the following personnel: Major H. Trumble (Cases 39, 65, 128, 134, 151, 180, 205, 221, 231 and 243), Lieutenant-Colonel B. K. Rank (Cases 248 and 310), and Wing-Commander C. Hembrow (Cases 40 and 170). There was no record of the surgeons responsible for the other operations. I was particularly fortunate in being associated with Major Trumble, who was responsible for the surgical side of this work and whose cooperation has been invaluable.

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# INTRACRANIAL HYDATID DISEASE, WITH REPORT OF A CASE.[1]

By Douglas Miller and Justin Fleming,
*Sydney.*

Hydatid disease of the cranial cavity is a rare condition. Cases have been recorded by Graham, Parry, MacCormick, Chisholm, Bird, Britten Jones and Hailes. In a large series of hydatids reported the percentage of brain cysts is 2·1%.[3]

The case described is one of primary hydatid cyst of the brain, and is reported because of its rarity and its unusual features.

Primary hydatid of the brain is confined usually to children, although cases occurring in adults have been described (Hailes).[2] The age incidence is 0·7% in adults and 4·9% in children. The average age of patients in cases recorded in Australia is eleven years. The condition is commoner in males, South American figures being 60% and Australian figures 64%.

The disease may be remarkably latent. The history, usually extending over three to four years, is characterized by the early onset of headache. Later, fits of the Jacksonian type may occur and may be followed by weakness.

The signs of a space-occupying lesion are usually present, and since the disease occurs during the growing period, the skull may become misshapen. There may be thinning of bone over the cyst, even to the extent of perforation. Such changes are obvious on radiographs. Calcification of the cyst is rare in cerebral hydatid disease.

Ventriculography may have to be employed in diagnosis, and one must be aware of the danger of passing the brain needle into the cyst. This could lead to secondary infestation. Serological reactions are unreliable in these cases and there is no characteristic finding in the cerebro-spinal fluid.

Eosinophilia may be present, but in children the possible association with helminthic infestations renders this of doubtful value. The finding of a hydatid cyst may therefore be quite unexpected.

## Pathology.

Eighty *per centum* of primary intracranial hydatid cysts are associated with an hepatic cyst.

In cases reported in Australia the left frontal lobe is the commonest site, although they may occur anywhere. One case reported by Britten Jones occurred in the cerebellum. The maximum incidence in the left hemisphere is possibly explicable on the grounds that the left common carotid, coming directly from the aorta, is likely to receive more hexicanth embryos than the right.

There is little reaction on the part of the nervous tissue to the presence of the cyst; hence adventitious ectocyst is usually poorly developed. The meninges in contact with the cyst wall show a reactionary thickening. The cerebral cortex may be thinned and markedly atrophied or the cyst may displace it with but little alteration of its structure.

Dew[3] draws attention to the large size of these cysts; some have contained up to twenty ounces of fluid.

[1] Accepted for publication on August 20, 1947.

**Daughter cyst formation is rare, as the blood supply is good and trauma minimal.**

## CASE REPORT.

A boy, aged eight years, was admitted to Saint Vincent's Hospital on June 26, 1946. He had lived in the country until the age of five and there were numerous sheep dogs in the vicinity of his country home.

At the age of four years he had had a fit which lasted four hours. Since then he had had six fits in all, the usual duration of each one being half to three-quarters of an hour. A typical fit started with gradual loss of consciousness, his voice faded away and he sank to the floor. Jerky movements then commenced in the right side of the face, right arm and right leg. The movements started together, there being no focal point of origin. They were regarded as idiopathic epilepsy.

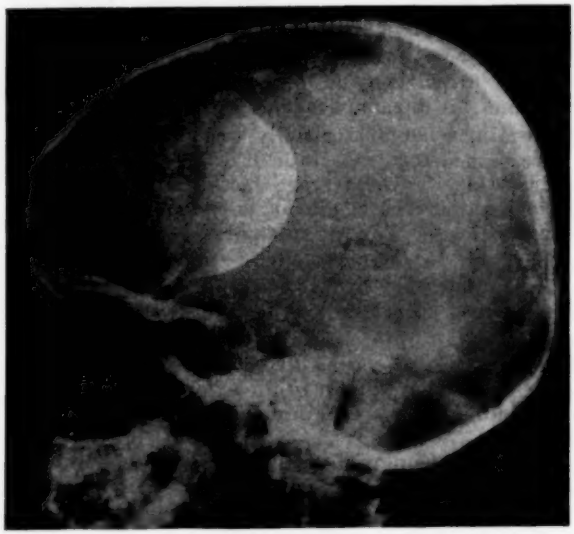

FIGURE I.

At the age of seven years the boy developed headaches, usually present in the morning. They were severe and were relieved by aspirin. Vomiting occurred only after a fit.

At eight years he was operated on for a bilateral internal strabismus.

Eight weeks before his admission to hospital the right arm became weak and the boy's parents noticed that he was using the left arm exclusively. Soon after this he began to drag his right foot. No fits occurred after the onset of paresis.

There was no complaint of impaired vision.

On admission to hospital he appeared well developed, bright and intelligent. The head appeared normal. Visual acuity was reduced in the right eye and the right visual field was contracted. He had a left internal strabismus. Papilledema was present in both fundi. He dragged the right foot and the medial side of the shoe was worn from heel to toe. There was weakness of the right side of the face, the right arm and the right leg, with deviation of the protruded tongue to the right. Abdominal reflexes were present and equal on both sides. The right plantar reflex was extensor.

X-ray examination of the skull (Figure I) revealed a calcified cyst in the left frontal region, the appearance being suggestive of a hydatid cyst. X-ray examination of the chest and abdomen showed no evidence of hydatid infestation. The result of the Casoni test was negative.

An exploratory operation was performed on July 8, 1946. An osteoplastic flap was turned down in the left fronto-parietal region. The dura appeared white and thickened.

This later proved to be fused dura and hydatid ectocyst. A cruciate incision was made over the site of the lesion and the four flaps were turned back and anchored.

Underlying this incised membrane were numerous daughter cysts and hydatid debris (Figure II). The walls of the parent cyst were irregularly calcified. The cyst was emptied of a very large quantity of daughter cysts and debris. At its posterior extremity a "break-through" was then seen and two large cysts were pulled forward through this opening. The parent cyst walls were rigid and showed no tendency to collapse. The removal of this wall was considered too formidable a performance. The wall was swabbed with eusol and the cavity and skull were closed without drainage.

There was a gradual uneventful recovery of consciousness. Return of power to the right arm occurred within two days of operation. The patient's progress was good, recovery of power in the leg and arm continued, the squint improved, and he was discharged from hospital on July 25, 1946.

Before discharge the Casoni test and the complement fixation test both gave strong reactions.

Two weeks after discharge from hospital almost all signs of paresis had disappeared.

On August 18, 1946, he was readmitted to hospital in an unconscious state. This followed several hours of headache and vomiting, culminating in a fit. Fits of short duration had recurred since, his respirations were stertorous, he was cyanosed, and clonic contractions of the right side of the face, right arm and leg were present, with conjugate deviation of eyes to the right. His temperature was 100° F. and his pulse rate was 140 per minute. The fits had to be controlled by "Avertin". His cerebro-spinal fluid pressure was 300 millimetres of water and the fluid was clear.

FIGURE II.

A brain needle was inserted through the old burr holes. A hard-walled cyst containing slightly blood-stained fluid was aspirated. Seventy-five cubic centimetres of fluid were obtained. Penicillin was introduced into the cyst cavity. X-ray examination showed a multilocular cyst cavity filled with air (Figure IIIA).

Three days later the child was quite alert, but had difficulty in articulation and paresis of the right face, arm and leg. The temperature was swinging.

On August 29, 1946, the cerebro-spinal fluid pressure was 200 millimetres of water and the protein content was 25 milligrammes *per centum*. No improvement in speech or power had occurred.

By September 2, 1946, the boy was drowsy and speaking in monosyllables. A brain needle was inserted again and the cyst aspirated. Twenty cubic centimetres of air were injected and an X-ray photograph was taken (Figure IIIB).

On September 17, 1946, ventriculography through posterior burr holes was done. The brain was under increased tension, the ventricles were greatly increased in size and the fluid was under increased pressure. Air was injected and X-ray photographs taken (Figure IV). The ventricular shift seen in X-ray films was thought to be due to the old cyst, though the cause of the ventricular distension was obscure. It was decided

to remove the calcified cyst wall. On September 29, 1946, a new osteoplastic flap was cut posterior to the previous one and continuous with it. When both flaps had been thrown down practically the whole hemisphere was uncovered. The old calcified cyst was then disclosed and behind it a rather large cyst, which was full of purulent-looking fluid and numerous daughter cysts. This cyst appeared to have escaped through the aperture in the original cyst which was noted in the first operation. It was removed and then the entire calcified cyst was carefully dissected out. This (Figure V) exposed the whole of the floor of the anterior fossa on the left side. A greatly compressed and atrophied brain was revealed. At one point the ependymal lining of the lateral ventricle lay exposed in the bottom of the cavity. It was difficult to see whether the cyst had replaced the brain by destruction from within or by pressure from without. As no fringe of cerebral tissue existed, it appeared to be an extreme pressure atrophy.

FIGURE IIIA.

As the large cavity appeared to be potentially infected, a small tube for penicillin irrigation was left *in situ* before closure.

On the day following operation the patient's pulse was rapid, but the general condition was good. There was slight neck rigidity. Aspiration of the drainage tube yielded cerebro-spinal fluid. Penicillin was introduced (200 units per cubic centimetre). On October 2, 1946, there was little or no change in his physical signs. Lumbar puncture revealed low cerebro-spinal fluid pressure. The leucocyte count was 11,000 per cubic millimetre. Neck rigidity had been constant and the child was irritable.

FIGURE IIIB.

On October 11, 1946, he was drowsy, irritable and emitted a high-pitched cry on attempted flexion of the neck. The cerebro-spinal fluid pressure was 300 millimetres of water, the protein content was 500 milligrammes *per centum*, cells numbered 220 per cubic millimetre and were mostly neutrophiles, but an occasional eosinophile cell was seen. No culture could be grown.

On October 12, 1946, ventriculography revealed large dilated ventricles under increased pressure. About 10 cubic centimetres of blood clot were aspirated from the site of the cysts. The patient showed little change and lay curled up in bed, resenting any interference. Neck rigidity was marked.

On October 14, 1946, ventricular tapping was repeated. The pressure was high and clear cerebro-spinal fluid was aspirated. The following morning the child developed twitchings in the limbs, although he appeared a little more alert.

It was decided to insert a needle anteriorly under the dura and drain the subdural space. Fifty-five cubic centimetres of fluid under increased pressure were removed and the needle was left *in situ*. Cerebro-spinal fluid drained from this. The boy became

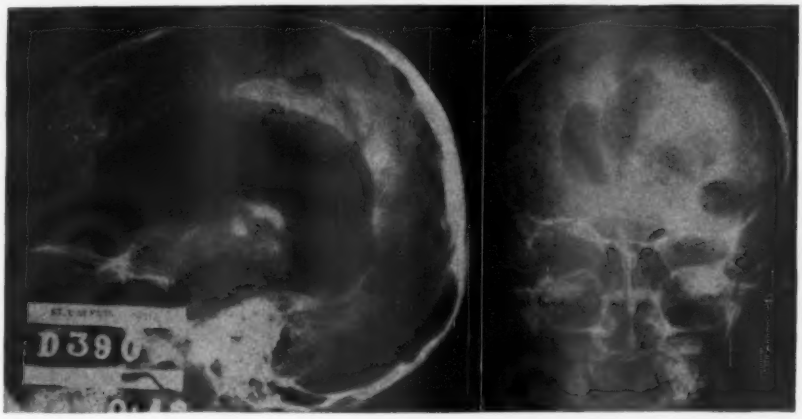


FIGURE IV.

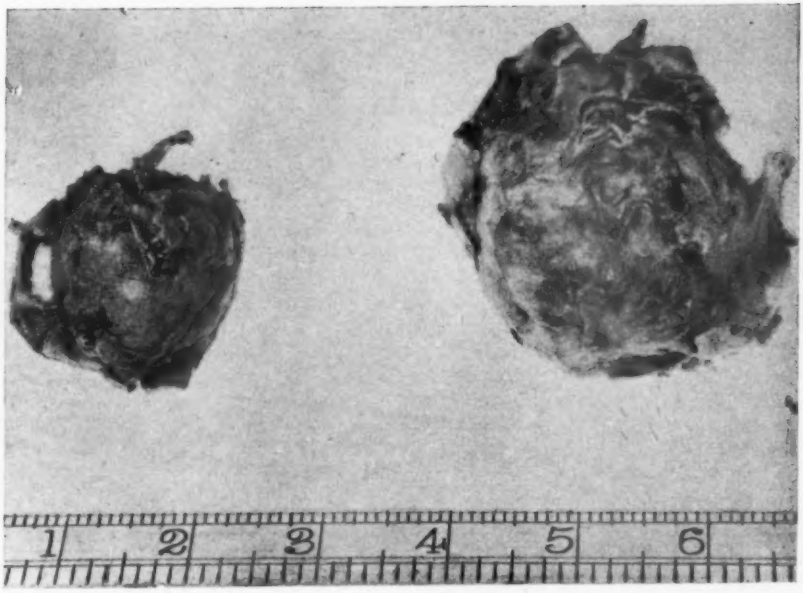


FIGURE V.

more alert and he remained the same for some twenty-four hours, when his condition deteriorated; he became unconscious with rapid respirations. The left arm twitched continuously until his death on October 19, 1946.

### *Post-Mortem Findings.*

There were no hydatid cysts in the cranial cavity. A basal meningitis was present, which had caused a ventricular obstruction. There was no hydatid infestation elsewhere in the body.

## COMMENT.

The case illustrates some interesting features. The patient's age and sex, the incidence and site of infestation conform with the usual story. The Casoni test gave no reaction and is of little help in the diagnosis of these conditions.

There was no sign of any associated hepatic cyst.

The presence of daughter cysts is unusual. Possibly the recurrent fits produced the trauma necessary for their production.

The adventitia was well developed and calcified. This is most unusual in hydatid disease of the brain. The X-ray signs thus produced enabled the diagnosis to be made with reasonable certainty before operation.

In this case apparently an aseptic meningitis developed following the first operation. This was probably due to contamination with an irritating fluid from the old calcified shell. In retrospect it would obviously appear to have been better to remove the calcified shell at the first operation.

## SUMMARY.

1. Primary hydatid cyst of the brain with calcification of the ectocyst and secondary echinococcosis is described.

2. The Casoni test gave a negative result.

3. Post-operative internal hydrocephalus developed.

4. Post-mortem examination disclosed a basal meningitis causing ventricular obstruction.

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# NERVE ANASTOMOSIS IN THE TREATMENT OF FACIAL PARALYSIS.[1]

By H. C. TRUMBLE,
*Melbourne.*

I HAVE employed the operation of hypoglossal-facial nerve anastomosis in the treatment of eighteen patients with facial paralysis and two with clonic facial spasm.

The twelfth nerve was selected as the donor nerve because of the close relationship between the muscles of the tongue and those of facial expression. It was first used for this purpose by Korte in 1901. Prior to this, in 1898, Fauré and Furet used the spinal accessory nerve as the "donor", and even today this may occasionally be preferable in cases in which it is important to avoid any interference with articulation, which may result from hemiatrophy of the tongue.

FIGURE I. Photograph of a boy, aged nine years, taken just before hypoglossal-facial nerve anastomosis was performed and twenty-six and a half months after the facial nerve had been damaged at operation on the middle ear. Complete facial paralysis on the right side.

In the treatment of two patients with clonic facial spasm the facial nerve was divided just below the base of the skull and its distal end was joined to the proximal end of the severed hypoglossal nerve at the same operation. In the majority of instances in the group comprising fifteen patients in whom the facial nerve had been destroyed at operation for the removal of intracranial tumours, anastomosis was resorted to as a rule a month or two after the main operation, but in one case there was a delay of three months and in two others a delay of nine and a half months. The longest interval between the time of the receipt of injury to the facial nerve and the date of the repair was twenty-six months. In this case the nerve had been damaged elsewhere at operation on the middle ear. Facial paralysis resulted from gunshot wounds in two patients. The operations for repair were carried out six and a half months after the receipt of injury in one case, nine months after injury in the other. The first signs of recovery of tone and voluntary movement in the muscles of expression were noted as a rule from three to four months after the anastomosis had been effected. In all but two cases recovery of tone was satisfactory and as a rule there was little abnormal to be noted in the appearance of the patient with the face

FIGURE II. Photographs of same boy as in Figure I, taken three and a half years after the reparative operation, to show recovery of function of the facial muscles. The boy is voluntarily contracting the muscles of the right side of the face.

[1] Accepted for publication on October 23, 1947.

in repose, excepting an absence of wrinkles in the forehead on the side of the lesion. One disappointing result occurred in a man aged thirty-four years. After removal of an eighth nerve tumour, hypoglossal-facial nerve anastomosis was effected. When seen six years afterwards, the face sagged as though the muscles of expression were completely paralysed, despite the fact that weak voluntary contractions could be initiated by the patient.

One patient who sustained a gunshot wound on November 1, 1942, was subjected to operation nine months later. Four months afterwards there was very slight return of power in the facial muscles. The patient resides in another State and has not been seen since. It is unlikely that the result in this case would be very good, as there was considerable damage to the cheek, maxilla and adjacent tissues at the time of the original wound.

FIGURE III.

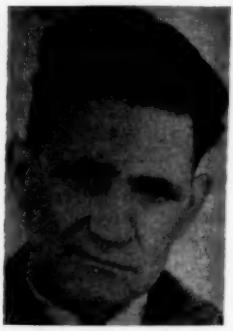

FIGURE IV.

FIGURE V.

FIGURE III. Photograph of a man, aged thirty-five years, taken two months after the left facial nerve had been destroyed at operation for the removal of a neurinoma of the eighth nerve, and one month after hypoglossal-facial nerve anastomosis had been performed, to show complete facial paralysis.

FIGURE IV. Photograph of patient depicted in Figure III, taken two and a half years after operation, to show recovery of function of facial muscles. The face is in repose.

FIGURE V. The patient depicted in Figures III and IV is voluntarily contracting the facial muscles which were previously paralysed.

With the exception of the patient just mentioned, voluntary movements returned in all cases—in the majority, of good power. At first patients would concentrate on moving the tongue in a particular way in order to activate the muscles of the face, but as time went on many of them seemed to think only of the face. Some did not know how they attained the effect.

Voluntary movements were best seen as a rule in the cheek and angle of the mouth, but the eyelids could usually be closed and the platysma and frontalis muscles participated to a lesser extent. Excepting in two cases there was no power of dissociation of movement, all of the muscles coming into play together. Two patients were able to set in action the muscles of the cheek without closing the eyelids, but could not close the eyelids independently.

In speaking, movements of the cheek and mouth occurred which, though not normal movements of expression, served to give a mobility to the face which was not displeasing. Blinking was noted in many cases. This was apparently not an active process in the affected lids, but due to inhibition of the levators of the upper lid in the presence of good tone of the *orbicularis palpebrarum*.

Hemiatrophy of the tongue occurred in all the patients. Despite this the tongue could be moved in all directions and mastication and swallowing

were quite efficient. Articulation was usually affected to a slight extent, at least for a time, but in most cases the disability was not very noticeable and as time went on it became less so.

It is interesting to note that whilst in two cases the anastomosis was carried out at the same operation as section of the facial nerve and in thirteen cases within three months of the date of onset of the facial paralysis, recovery was no better than in those cases in which there was a considerable delay. Recovery in one patient in whom repair was effected twenty-six months after the onset of paralysis, due to injury of the facial nerve in the middle ear, was so good as to suggest that the need for haste in repairing nerve injuries has been over-emphasized. The muscles and end plates in this case, twenty-six months after the date of the nerve injury, had evidently not degenerated to any serious degree. It would seem, therefore, that it is not unreasonable to resort to nerve anastomosis in the treatment of facial paralysis, even though this has been present for two years. It remains to be proved whether a similar satisfactory result could be obtained after the lapse of a longer period.

FIGURE VI.

FIGURE VII.

FIGURES VI and VII. Photographs of a woman, aged fifty-two years, who previously had suffered from clonic facial spasm. The left facial nerve was divided at the stylo-mastoid foramen four and a half years before the photograph was taken, and at the same operation hypoglossal-facial nerve anastomosis was performed. The photographs show recovery of tone and voluntary power in the facial muscles on the left side.

No particular care was taken of the facial muscles either before or after operation in any of the cases. Splinting, massage and electrical stimulation were not employed at all in most instances, and this apparently did not adversely affect the final results.

Clonic spasm was immediately and completely relieved by section of the facial nerve in two patients who were very grateful and pleased with the final result.

## SUMMARY.

Results obtained in the treatment of facial paralysis and clonic facial spasm by means of the operation of hypoglossal-facial anastomosis are described. Recovery of tone and voluntary power was satisfactory in eighteen patients, unsatisfactory in one. One patient has not been reviewed. Recovery was very satisfactory in two cases in which there was a delay of nine and a half months between the date of onset of facial paralysis and that of the reparative operation, and also in one other in which the delay was twenty-six months. These observations would seem to demonstrate that degeneration of muscle fibres and end plates is not of such importance as is generally believed.

## Case Reports.

# ISCHIO-RECTAL URINARY FISTULA: REPORT OF A CASE.[1]

By H. G. CUMMINE and M. S. S. EARLAM,
*From the Department of Urology, Royal Prince Alfred Hospital, Sydney.*

THE patient, W.C., aged seventy-two years, was admitted to the Royal Prince Alfred Hospital on October 1, 1945, suffering from many urinary fistulæ in the left buttock. There was evidence of considerable loss of weight. A suprapubic tube draining the bladder was in position. He had been in another hospital since September 18, 1944. In brief, the history was as follows. In 1938 a transurethral resection of the prostate for lateral lobe hypertrophy was performed and an acute prostatic abscess developed during convalescence. This drained *per urethram* and he was discharged from hospital

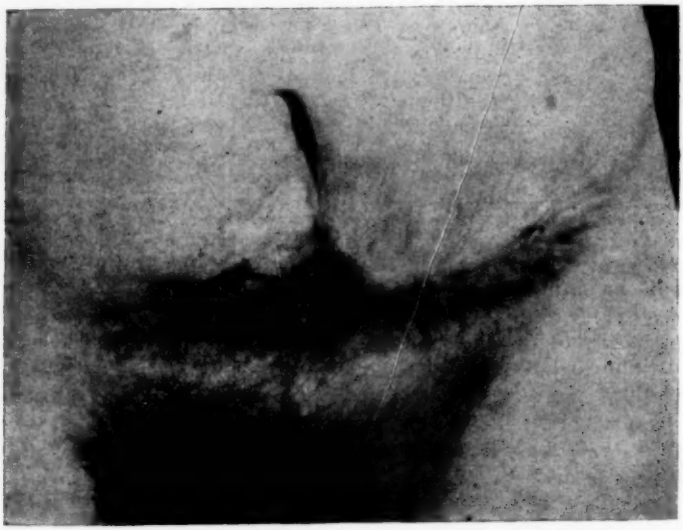

FIGURE I.

three months after the operation. He presented himself again for attention at a different hospital in September, 1944, complaining of a lump in the left buttock, which, he stated, had been present for a year and was gradually increasing in size. It had been painful for the last three months.

On examination a tender, firm swelling was found between the left greater trochanter and the ischial spine, approximately three inches in diameter. This was incised and a lobulated mass filled with necrotic debris was exposed. Purulent discharge occurred for about a week and then urine was passed from the wound at each act of micturition. Radio-opaque material injected into the bladder was demonstrated in the pelvic soft tissue and buttock sinus.

To divert the urinary stream from the sinuses a suprapubic cystostomy was performed on October 20, 1944. Unfortunately a spreading symbiotic gangrene developed on the anterior abdominal wall, from which *Bacillus coli communis* and non-hæmolytic streptococci were grown in culture. The whole area was excised with a diathermy

[1] Accepted for publication on January 21, 1947.

knife on November 20, 1944, and dressings of zinc peroxide were applied. Healing occurred slowly with considerable plaque-like scarring (Figure I).

Meanwhile the buttock sinuses increased in number and discharged free pus. Cultures of this demonstrated streptococci, *Bacillus coli communis* and Gram-negative bacilli. These sinuses did not respond to irrigations with monacrin or gramicidin solutions. Whilst the suprapubic tube was allowed to drain, no urine came through the sinuses unless voluntary micturition was attempted. Very little urine, however, could be passed *per urethram*.

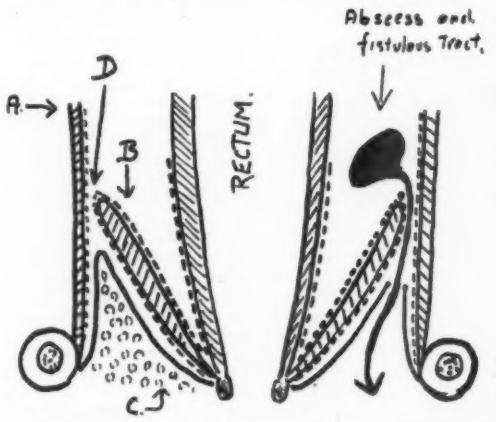


FIGURE II. A = *obturator internus* muscle with covering fascia. B = *levator ani* muscle with covering fascia, C = fat in ischio-rectal fossa separated from the fascia of A and B by the dense *fascia lunata* of Grafton Elliot Smith, D = the hiatus of Schwalbe, which represents a gap between the upper margin of the *levator ani* muscle and its line of origin from the fascia of the *obturator internus*. This gap is present in a small percentage of cases. (After Lee McGregor.)

At this stage the patient was transferred to the urology department, Royal Prince Alfred Hospital. Examination revealed a large central sinus with thick fibrous walls opening into the left ischio-rectal fossa. Branches from this ran up onto the left buttock with many superficial openings. On rectal examination the prostate showed well-marked adenomatous enlargement, and gentle massage expressed pus *per urethram*.

The patient was in fairly good condition. His blood urea content was found to be 43 milligrammes *per centum*. There were 18,100 leucocytes per cubic millimetre (neutrophile cells, 78%; lymphocytes, 15%; monocytes, 5%; eosinophile cells, 2%). The hæmoglobin content was 102% normal and 14·8 grammes *per centum*. Plain radiographs of the pelvis did not reveal any form of chronic osteomyelitis or retained opaque foreign body. The lung fields were clear of tuberculous infection. Smears and cultures of the sinus discharge demonstrated *Bacillus proteus*, *Bacillus coli* and non-hæmolytic streptococci. This last-mentioned organism was also present on anaerobic culture. No actinomyces or tubercle bacilli were found. Urine culture yielded bacilli of the coliform and protean variety.

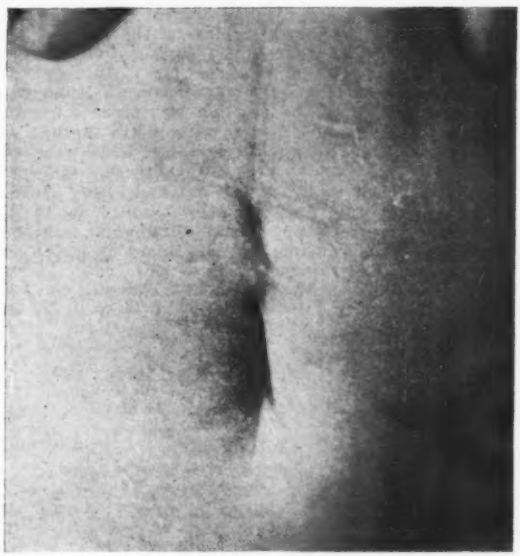

FIGURE III.

On October 8, 1945, cystoscopy was carried out to detect, if possible, a fistulous opening into the prostatic urethra. This was not found.

Local lavage was persevered with and a high vitamin diet was commenced. Potassium iodide in saturated solution was given in graduated doses until a dose of one fluid ounce thrice daily was achieved. Considerable decrease in the amount of the purulent discharge occurred, and on November 8, after 800,000 units of penicillin in 20,000-unit

doses at three-hourly intervals had been given, the contents of the left ischio-rectal fossa were dissected out *en bloc* and the main sinus was found to be coming through the hiatus of Schwalbe at the apex of the fossa (Figure II). The fossa was packed with "Vaseline" gauze after implantation of sulphanilamide powder. The superficial sinuses in the buttock were all laid open and converted into a single wound. This was sutured after implantation of sulphanilamide powder.

FIGURE IV.

The patient was then immobilized in a posterior gutter plaster cast and nursed on the right side to promote adequate drainage. By January 10, 1946, all the buttock sinuses had healed (Figure III), while the opening of the ischio-rectal fistula was pinhole, with a little discharge persisting. Urine could still be forced through this latter orifice. The patient was taken out of the plaster cast and a trans-urethral removal of the right adenomatous lobe was performed. An acute prostatitis occurred after this, but was controlled with penicillin and full drainage from the urethra for several days by gentle massage *per rectum*. The left lobe was removed transurethrally on January 24, 1946. No prostatic flare-up occurred on this occasion, the patient having been kept continuously on penicillin as a prophylactic measure. Gentle prostatic massage was always rewarded by free pus draining from the urethra. On May 15, 1946, as the urethral stream was excellent when tested by clamping off the suprapubic tube, this latter was removed and the patient became ambulant. The suprapubic fistula closed after a week, during which a Hamilton-Irving box was used. On July 4, 1946, urethroscopy was carried out and numerous small purulent sinuses were found on either side of the verumontanum, which emptied when the prostate was pressed *per rectum*. Ten days later the patient was discharged with a good stream, slight urethral discharge on prostatic massage and a pinpoint sinus (Figure IV) in the left ischio-rectal fossa, over which he wore a pad. He reported for regular prostatic expression and after two months this was no longer productive and was suspended.

When last seen on September 30, 1946, he had put on more than half a stone in weight and was a happy social unit. The ischio-rectal sinus had almost completely closed and discharge was a "stain" only on a daily pad. No urine passed through the sinus unless he strained. It is a sober reflection that he still has the frequency for which he initially sought medical treatment.

# CARCINOMA OF THE BREAST IN HUSBAND AND WIFE.[1]

By VICTOR COPPLESON,
*Sydney.*

THE occurrence of carcinoma of the breast in a husband and wife is at the least a strange coincidence. No report of a similar case can be found in the literature. From available statistical data it would seem that the chances of both husband and wife dying of carcinoma of the breast is about 1 in 100,000.

The husband, aged fifty-one years, first reported in May, 1943, suffering from a slight eczema of the right nipple. There was an underlying lump in the upper outer quadrant of the breast, which he attributed to a "knock" he had received three months previously. He was admitted to hospital and a radical excision of the breast was performed. Microscopic examination of the tumour showed it to be a scirrhous carcinoma. No metastasis was found. After some severe exertion early in 1947 he complained of severe pain in the left side of his chest and died suddenly several days later whilst going home from work.

In April, 1946, his wife reported. She complained of a swelling in the right breast of six months' duration. A lump was present in the upper medial quadrant of the breast. There was some attachment to the skin and the nipple. Some glands were palpable in the axilla. There was a history that in 1928 a small lump had been removed from the breast, which examination showed to be innocent. She was admitted to hospital and a radical excision of the breast was performed. Microscopic examination of the breast showed the tumour to be a fairly fast-growing scirrhous carcinoma with extensive metastases in glands.

The patients had been married for thirty-one years and lived all their lives in Sydney. They have two children, a son and a daughter. The son was born with ichthyosis, not of severe degree. The daughter died from bronchitis at the age of two. The son is married and has a daughter.

On the husband's side, his mother had died ten years ago, aged seventy-eight years, after a fracture of the femur. A sister of his mother had died forty years ago and had had three operations on the breast for cancer. Two brothers had lost their lives in the 1914-1918 war and the other during the recent war. Of two sisters, one, aged seventy-four years, is in good health; the other, aged seventy-nine years, has had a pelvic operation, but no trouble with her breast.

On the wife's side, a cousin on her father's side had her breast removed for cancer three years ago. There are two sisters alive, one of whom has some trouble with her breast of long duration, the nature of which is not known. Of three brothers, one died after his ship was torpedoed; the others are well.

### Statistical Considerations.

I am indebted to Dr. H. O. Lancaster for the following statistical information.

The Registrar-General, England and Wales, gives the following information for cancer of the breast for the years 1922 to 1942 inclusive:

| All Ages. | Male. | Female. |
|---|---|---|
| Cancer of breast .. .. | 1,094 .. | 128,931 |
| All deaths .. .. .. .. | 5,227,000 .. | 5,014,432 |
| | 1 | 1 |
| | 4,778 | 38·9 |

Female rate = 2·571% of all female deaths = 1/38·89.

Male rate = 0·0209% of all male deaths = 1/4,778.

A rough calculation of a given male and given female both dying of cancer of the breast in England in the period 1932-1942 is as follows:

$$\text{Probability} = \frac{1}{4{,}778} \times \frac{1}{38{\cdot}89} = \frac{1}{185{,}800}$$
$$= 0{\cdot}00000538$$
$$= 5{\cdot}38 \text{ in million.}$$

[1] Accepted for publication on August 20, 1947.

Comparable figures from Australia for the years 1936-1945 inclusive are as follows:

Males .. .. Breast to all deaths $= \frac{1}{5{,}336} = 0{\cdot}0001874$

Females .. Breast to all deaths $= \frac{1}{37{\cdot}75} = 0{\cdot}02649$

The probability that a given male death and a given female death are both due to cancer of the breast is as follows:

$$\frac{1}{5{,}336} \times \frac{1}{37{\cdot}75} = \frac{1}{201{,}400} = 0{\cdot}00000496$$

For man and wife the odds are probably of the order of $\frac{1}{100{,}000}$, since the deaths above are at all ages.

# HYDATID CYST OF THE RIGHT KIDNEY.[1]

By J. B. G. Muir,
*Hobart.*

The following case of a hydatid cyst of the right kidney is submitted merely to illustrate the typical history of the condition and to describe the extraordinarily fine specimen of the disease obtained at operation.

## History.

H.P., a male, aged thirty-two years, a farmer, gave a history of intermittent attacks of severe pain in the right loin, radiating downwards and forwards towards the groin, over a period of eight years and occurring at intervals of about eighteen months. Each attack of pain was associated with some hæmaturia and the occasional passage of pieces of tissue resembling grape skins in the urine. In all other respects his health had been satisfactory.

On examination the patient was a healthy-looking, well-built man. His heart and lungs were clear on clinical examination, and no mass or enlargement of any viscus was noted on abdominal palpation. An appendicectomy had been performed in childhood. Examination of the urine on his admission to hospital revealed a slight trace of albumin.

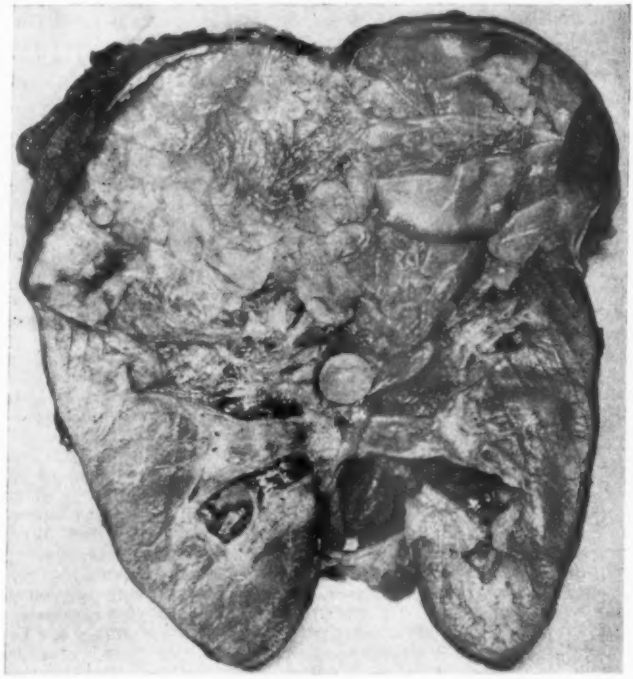

Figure I. Hydatid cyst of kidney. × ⅓.

Excretion pyelography showed good excretory function of the left kidney with a normal renal pelvis but a completely non-functioning right kidney. Cystoscopy demonstrated good left ureteric excretion, but no excretion from the right ureter. Retrograde pyelography showed on the right side an irregular cavity in the upper part of the right kidney, but a normally shaped left renal pelvis.

A differential white cell blood count revealed 4% eosinophilia, and the Casoni skin test gave an "immediate positive reaction".

The case appeared to be typical of hydatid cyst of the right kidney, and nephrectomy was advised. This was carried out on July 14, 1947, under ether anæsthesia, through the usual right loin incision.

[1] Accepted for publication on December 17, 1947.

The kidney was found to be considerably enlarged in the upper pole by a cystic swelling the size of a large apple, which was very adherent to the peritoneum and duodenum anteriorly. It was necessary to resect the twelfth rib to enable the upper pole to be safely dissected free without rupture before the kidney could be removed intact.

The patient made an uneventful convalescence.

### Pathology.

The specimen consists of the right kidney, the whole upper segment being replaced by a hydatid cyst containing numerous daughter cysts. From time to time rupture of the parent cyst had occurred into the renal pelvis, with the escape of daughter cysts down the ureter causing attacks of renal colic and hæmaturia.

# Surgery in Other Countries.

*[In this column will be published short résumés of articles likely to be of practical value from Journals published in other countries and not readily accessible to surgeons in Australia and New Zealand.]*

## HEMIPANCREATECTOMY FOR STONE.

**P. Mallet-Guy, P. Marion and R. Jeanjean:** *"Indications et résultats de la pancréatectomie gauche dans la lithiase du canal de Wirsung"*, *Lyon chirurgical*, Volume xli, 1946, page 661.

THE accepted method of treating lithiasis occurring in the pancreatic duct is to open and drain the duct, having removed the stones. The present authors consider that resection of the left half of the gland is a more satisfactory method, especially in that form of lithiasis in which there are present large stones in a dilated and infected duct. The older mode of attack was accompanied always by risk of fistula formation, risk of recurrence of the symptoms, and by risk of actual aggravation of the symptoms owing to fresh infection introduced by way of the drainage tube. There are here reported three cases in which hemipancreatectomy was performed, each one illustrating a different aspect of the subject.

The first patient, a woman aged twenty-three years, had suffered repeated attacks of abdominal pain for nine years, although she had had free intervals of as long as two years between them. Chronic pancreatitis had been diagnosed seven years before her admission to hospital. Radiological examination carried out prior to the operation revealed batches of calculi both to the right and left of the vertebral column. At operation there was found a diffuse sclerosing pancreatitis, with collections of calculi in the head and also in the tail of the gland. The left half of the pancreas was resected, together with the spleen, and a gauze wick with a drainage tube was laid down to the ligated end of the pancreatic duct. The duct was then opened in the head of the gland and as many as possible of the calculi found there were removed. The opening in the duct was drained. The final step was a cholecystostomy, although the biliary tracts were to all appearances normal. The drain in the head of the pancreas was removed on the twenty-fifth post-operative day, that to the stump on the thirty-seventh, the cholecystostomy tube being retained somewhat longer. The post-operative course was all that could be desired and the patient is in excellent health twenty-seven months after the operation. The resected half of the gland was gravely altered, with a diffuse sclerosis throughout and many dilated ducts forming pseudocysts of varying size. Thrombosis was evident in several of the smaller veins. The lesions in the head of the gland must necessarily remain with no more done for them than drainage, but although recent X-ray examinations show that several stones remain in this part of the duct, there have so far been no symptoms from them.

The second patient reported is one in whom for a condition similar to that just recorded, right-sided and left-sided pancreatic drainage was instituted as a curative operation. A large branched calculus was removed with some difficulty from the head of the gland, and after a passage was made through the lesser sac, numerous stones were encountered in the tail of the gland, necessitating an incision in the duct 7·0 centimetres long for their extraction. Drainage was efficient, some 200 cubic centimetres of pancreatic fluid escaping from the two tubes in the first three days; and it was maintained on the left side for twenty days, on the right for thirty-nine, while the gall-bladder was drained for three months. For five months after this operation the patient seemed to be cured, but thereafter her symptoms recurred, mainly left-sided pain, and six months later she was in as bad a condition as she had been before her operation. It was then decided to resect the left half of the pancreas and after a technically very difficult operation, the surgeon working through an obliterated lesser sac and dissecting out a densely sclerosed, almost unrecognizable pancreas from surrounding sclerotic tissue, this was successfully accomplished. The post-operative course was marked by several successive hæmorrhages, requiring repeated blood transfusions, but thereafter the course was uneventful. The striking feature of this case was that while the left half of the pancreas was found to be grossly diseased, the right half at the second operation was seen to be apparently almost normal, and this strengthened the impression gained from the first case, that the right half of the gland reacts well to drainage, but that it is the left half of it, that part "distal" to the interruption in the duct, which shows progressive disease.

In the third case, therefore, it was decided to omit the separate drainage of the head of the gland, but instead to resect the pancreas as far to the right as possible. It was found possible to do this right across the middle line until the calculus lying farthest to the right could be extracted from the open stump of the severed duct. Here again the greatest degree of sclerosis and inflammatory reaction, as well as the greatest technical difficulty, was found to the left, the dissection becoming progressively easier as the mid-line was approached. The operation in this case was terminated by the interposition of a piece of omentum between the stump of the pancreas and the portal vein. No difficulties were encountered in the post-operative course, and three months after the operation the patient reports himself entirely well. Blood sugar estimations undertaken during the first weeks after the operation showed no significant changes from the normal, although the segment of pancreas resected weighed 24 grammes and was 9·0 centimetres in length.

The lessons to be learned from these cases are apparently that wherever the calculi are situated, it is the left half of the gland, the "distal" part, which sustains the brunt of the pathological damage, and that the surgical removal of this part is therefore a rational and hopeful method of treatment.

ARTHUR E. BROWN.

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## TOTAL PROSTATECTOMY FOR CANCER.

**R. Gouvernour and A. Dufour:** *"La prostatectomie totale sus-pubienne dans le cancer de la prostate"*, *Revue de chirurgie*, Volume lxv, 1946, page 13.

THE attitude generally adopted towards cancer of the prostate has been one of pessimism, active treatment being limited to palliative resections or radiotherapy. There are, however, a certain number of such cases amenable to radical resection of the gland with a hope of cure, and this number would increase could our powers of diagnosis in the early stages be improved. Unfortunately, in many cases, by the time symptoms have arisen the growth has usually gone beyond the reach of active surgery. Dysuria in primary carcinoma is an indication of diffuse spread, though when the carcinoma arises as a degeneration in an adenoma radical resection is often still possible. The main diagnostic problem is to distinguish between the two conditions. Rectal palpation gives information of great importance when the anterior lower limits of the gland are carefully examined, and also the lateral sulci, and more especially the region between the two vesicles. A limited circumscribed induration is no bar to surgery, but any diffusion in the perivesicular tissues or any adherence of the rectal wall is an absolute contraindication. Cystoscopy should reveal no involvement or ulceration of the trigonal area. Urethroscopy generally indicates nothing more than an elongation of the supramontanal fossa. In those cases in which ulceration or fungation of the posterior portion of the urethra prevents satisfactory examination of this posterior portion, rectal palpation should already have given the information that the condition is inoperable.

A tumour of moderate size, well limited, not diffusely indurated, is suitable for surgical removal, always supposing that general examination has excluded the likelihood of metastatic deposits elsewhere. Such removal must include the whole gland, with its capsule, the suprajacent vesical mucosa, the two seminal vesicles and the terminal portions of the *vasa deferentia*. Resection by the perineal route is mentioned only to be briefly dismissed, the operation being performed by the suprapubic approach under spinal anæsthesia and with the aid of the diathermy knife.

The bladder is exposed and its anterior wall is mobilized by the usual technique to ensure a good view of the bladder base. The ureters are catheterized only if they come too close to the area of resection and are likely to suffer damage. The vesical mucosa is incised with the diathermy knife to a depth of 4·0 to 5·0 millimetres in a circular fashion surrounding the prostatic prominence, this circle being as generous in its diameter as the ureters will safely allow. Two fingers of the left hand are inserted into the rectum to assist by touch the further dissections. Curved scissors deepen the incision anteriorly and the gland is pulled up by forceps placed on the anterior lip of the urethral orifice. The mass is freed laterally by finger and scissor dissection and the urethra is cut across. The posterior dissection is more difficult, as it includes dissection of the fibrous tissue containing the prostato-vesicular vessels, the vesicles and the vasa. Provided, however, that the condition has properly been adjudged suitable for operation, a plane of cleavage can be found which permits of finger and scissor dissection. The vessels are caught and tied, and the vesicle is separated from the rectum. This is sometimes difficult and a small portion of the vesicle may have to be left attached to the rectal wall. Should this portion be too large or be obviously affected by the growth, it is wise to implant one or two radium needles into it under vision before terminating the operation. Several small vessels will require tying during the stage of separation of the vesicles, but, after this, bleeding is slight. When the posterior dissection has been completed and the mass removed,

the fibres of the rectal wall are exposed in the bottom of the wound, this indicating a truly extracapsular resection. The cavity is cleared of clots and subjected to some compression. It is then fully packed with gauze, a Freyer type drain tube is put into the bladder, and the skin is closed round it, the tail of the gauze and a small tube in the space of Retzius.

Such a prostatectomy has the following advantages. It is a one-stage proceeding. It permits, before the bladder is opened, an exploration of the hypogastric gland area. It can be performed throughout under clear vision and causes a mortality little greater than that attaching to simple removal of adenomata. The post-operative course is smooth. The authors found occasion to use it on twenty-four patients with satisfactory results, which they do not report in detail, but they recommend it to other surgeons for use in suitably chosen cases.

ARTHUR E. BROWN.

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## RECURRENT DISLOCATION OF THE SHOULDER.

**Torsten Jerre:** *"Eine Modifikation der Nicola'schen Operationsmethode bei habitueller Schultergelenkluxation"*, *Acta chirurgica Scandinavica*, Volume xcv, 1947, page 1.

DISSATISFIED with the various operations so far planned for the cure of recurrent dislocation of the shoulder joint, K. Stenport, working at the Krüppelanstalt in Helsingborg, commenced in 1943 to use the following technique in these cases.

With the patient's arm at a right angle to the body an incision was made from the acromio-clavicular joint distally for about ten centimetres along the anterior border of the deltoid. The *pectoralis major* with the cephalic vein was drawn inwards and the deltoid outwards, when rotary movements of the humerus permitted easy identification of the greater tuberosity and the intertubercular sulcus. The transverse humeral ligament overlying the sulcus was cut through and the tendon of the long head of the biceps was exposed and dissected free over the joint; the capsule of the joint must be cut through and opened in so doing. The arm being then rotated outward, the lesser tuberosity and the parts immediately medial to it came into view. The next step consisted of cutting through the insertion of the subscapularis muscle to the lesser tuberosity and the crista immediately below it. A groove was then cut by chisel immediately medial to the lesser tuberosity, and in this groove the displaced tendon of the long head of the biceps was placed and sutured. The attachment of the tendon of the subscapularis to the tuberosity and the crista was reconstituted and the wound was closed. An abduction splint, holding the arm at 90° of abduction and 30° in front of the body plane, was worn for fourteen days, only the first two of which were spent in bed. Active movements were commenced immediately after the splint was discarded.

Nicola's operation and its many modifications are based not on any pathological and anatomical concept, but are planned solely with the object of keeping the head of the humerus bound to the glenoid fossa. But the existence of a pathological and anatomical basis for the condition of recurrent dislocation has much evidence to support it. It occurs mainly in young people, while traumatic dislocation is seen mostly in those of older age groups. Recurrent dislocation is seldom associated with rupture of the supraspinatus tendon or with fracture of the greater tuberosity, both of which frequently occur with the ordinary traumatic dislocations. Other similar differences have been pointed out by various authors, and this has led to the supposition that traumatic dislocations pass on into the recurrent form only if a congenital predisposition to it exists. Bankart and Watson-Jones and others consider traumatic and recurrent dislocation to be two entirely different entities, although they allow a special form of traumatic dislocation to be the originating cause of the habitual luxation; and Bankart has based his operation upon repairing the gap torn between the *labrum glenoidale* and its bony attachment.

Stenport's operation has the following advantages: it is simpler in execution; it requires only a minor incision into the joint capsule; it necessitates no damage to the articular cartilage; and it does not include any section of the tendon of the long head of the biceps. Finally, the position in which the displaced tendon is fixed is more medial than in other variations of Nicola's operation, including that of Roberts, and this is mechanically important. Jerre reports nine cases in which the results appear to be uniformly good, although he recognizes that insufficient time has elapsed since the introduction of the operation to render these results strictly comparable with those of the older type of technique, in which very late recurrences have been recorded.

When the results of Nicola's operation are compared with those following operations after the type devised by Eden-Hybbinette and Bankart, the comparison is much in favour of the latter type. In a collection of 169 cases operated on by Eden-Hybbinette's method by various surgeons there was only one case of spontaneous recurrence. In a

review of 114 cases operated on by Bankart's technique by five surgeons recurrence was noted in only one patient, an epileptic. No series of Nicola's operation results of comparable size can show similar results. The main fault in Nicola's operation appears to lie in the tendon of the long head of the biceps, which may chafe through in its bored canal through the head of the humerus, or may show weaknesses at the suture line. Section and suture of this tendon are an inherent weakness in this operation. Roberts's modification, which avoids this fault, gives better results, though only in small series. The Stenport operation here reported has this advantage along with its others over the original, while in comparison with the technique of Eden-Hybbinette and Bankart it can be said that it is a much smaller, simpler operation and that the stay in hospital as well as the period of disability is much shorter. Only time will show if late recurrences will neutralize these advantages, but for the present it would appear that this simple, effective procedure is worthy of more general adoption.

ARTHUR E. BROWN.

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## PARAFFIN TUMOURS IN THE PENIS.

**J. Quénu and E. Pérol:** "*Des paraffinomes de la verge*", *Journal de chirurgie*, Volume lxiii, 1947, page 345.

THE occurrence of paraffin tumours in the body is well known, but their appearance in the penis is rare, and the treatment of them presents some very difficult problems. Five cases have been reported in the literature, to which the authors add a sixth.

The patient, a man of forty-five years, stated that in 1936 there had appeared on the sides of the penis two small nodules which had later coalesced and formed a collar. In 1942 the lesions developed surface fissures and, in 1943, ulcerations, which had now formed one large ulcer over the whole dorsum of the organ. A diagnosis of carcinoma had been previously made, also that of scleroderma. Finally a biopsy provided proof that the condition was in fact due to paraffin. The patient denied any venereal infection and was resolute in maintaining that at no time had he or anyone else injected paraffin or any other substance into the penis. He attributed the condition to an injection of an unknown substance into his flank by a German army doctor while he was a prisoner of war in 1918. In spite of the microscopic diagnosis of paraffinoma, the clinical appearance was so suggestive of malignancy that the inguinal glands were removed and also submitted to histological examination. On first examination these were reported to have the typical appearance of tuberculosis or of Boeck-Schaumann's disease. On further acquaintance with the patient's history they were reexamined and on this occasion certain points were noted that had been previously missed. For example, very careful study of the fibrous structures at the periphery of the gland showed that what had been taken to be fat cells were really minute collections of a homogeneous substance, the appearances being almost masked by intense sclerosis. It was then established that the glands were definitely involved in the pathological changes arising from the paraffin.

These tumours are apparently always caused by the deliberate injection of masses of paraffin or "Vaseline" under the skin of the penis. The injection has always been performed by non-medical persons, with the vain hope of increasing the size of a functional organ. Only in one of the recorded cases was the object different, and in that one it was stated to have been done to get rid of tattoo markings. The present case does not have the same evident origin, but the authors show a discreet scepticism towards the patient's denials, in view of all the circumstances of the case.

The quantities of paraffin or "Vaseline" injected have varied between 20·0 and 80·0 cubic centimetres. The injection is apparently painless, but is followed swiftly by an œdematous reaction which entirely prevents coitus. The later evolution is towards encapsulation by excessive connective tissue reaction and also towards inflammatory effects, abscess, fistula formation, ulceration or attacks of lymphangitis. The clinical course is very variable. Surgical help may become necessary within a few months, as in Marquardt's case, or not be asked for for ten years, as in that of Leger. The glans is never affected, but the prepuce may develop enormous dimensions, either of a phimotic or a paraphimotic type. It not only prevents sexual function but may even interfere with micturition. In some cases, as in the one here reported, the prepuce may be completely destroyed by ulcerative action. The main pathological changes are to be found in the loose cellular layer between the skin and the body of the penis. This is transformed into a hard cylindrical shell, often several millimetres thick, which by its contraction shortens and tightly encases the penis, rendering expansion and erection impossible. The penis may be enormously enlarged in circumference and is always of an abnormal consistency, which is not uniform, but consists of irregular bosses in various places. The infiltration spreads downwards from the root of the penis, forming plaques on either side of the scrotum, and may entirely enclose the testicles, which, on the other hand, are always unaffected by the process.

The infiltration may also spread downwards into the perineum or upward into the suprapubic region. In some cases, as in the one here recorded, the inguinal glands are involved and histologically are seen to contain small droplets of paraffin enclosed by intensely sclerosed tissue. The passage of paraffin by the lymphatics has been known since Favre and Civatte wrote in 1920, but it has not been reported prior to this case that the inguinal glands can be involved from a paraffinoma of the penis.

Diagnosis would not present much difficulty were it not for the reticence of the patients. It was this factor in the present case which caused both scleroderma and carcinoma to be seriously considered. Biopsy either of the penile skin or of an inguinal gland should put the matter beyond doubt, but it must be noted that the sections must be studied with very great care, paraffin tumours being of such comparative rarity.

The nature of the treatment depends largely upon the stage at which the lesion has arrived at the time when surgical management is undertaken. If one is fortunate enough to meet with an early case, all that is necessary is to make incisions and to evacuate the paraffin. Marquardt was able to do this in his case, seen only three months after the injection had been made. Fischer, whose patient came to him a year after the injection, was also able to deal simply with the lesion. But most cases seen are old cases with diffuse fibrous lesions, with retractile sclerosis and skin infiltration, calling for excision rather than for incision, and operative treatment must then go through the two stages of resection and then reconstruction. First, the paraffin lesions must be resected, including the sclerotic sheath of the penis, as well as the extensions to the perineum, scrotum or suprapubic tissue. This may present extreme difficulty. Morestin mentions the "enormous difficulty" which he encountered in dissecting out the yellowish masses everywhere adherent. Estrade had to use three separate stages to remove the diseased tissue from his patient. In every case one must expect to be left with a tissue deficiency formidable in its extent. Repair must include part or all of the cutaneous envelope of the penis, and the difficulty will of course correspond with the amount of this that requires replacement. In the case presented here the penis was left with no skin at all, and in this denuded state it sprang from a large also denuded area extending from the pubis to the scrotum. A skin flap was nowhere available except from the inner side of the thigh, or from the abdominal wall. One was eventually constructed in the left abdomino-inguinal region. Healing is rarely a simple process, being hampered by hæmatomata which are almost inevitable with such a dissection in a very vascular area. And the skin edges do not heal smoothly but are apt to slough in an annoying manner. The author's patient spent no less than six months in hospital undergoing repairs.

Eventually he obtained a penis of a certain "tailored" appearance and afflicted by some patches of unwanted hair, but of normal length, calibre and consistency and fully capable of expansion and erection. The patient expressed himself as well satisfied with the functional result of the operation.

ARTHUR E. BROWN.

## Reviews.

**Pictorial Handbook of Fracture Treatment.** By E. L. COMPERE, M.D., F.A.C.S., SAM W. BANKS, M.D., F.A.C.S., and C. L. COMPERE, M.D., F.A.C.S.; Second Edition; 1947. Chicago: The Year Book Publishers, Incorporated. 8″ × 5¼″, pp 390, with 191 figures. Price: $5.50.

IN their preface to the first edition the authors have accurately anticipated the reaction of a reviewer to the appearance of their volume, namely: Why another book on fractures?

But this book is something different. Written for the general practitioner, it essays to give the best method of treatment of all the commonly encountered conditions. Many of the methods are far beyond the capabilities and resources of the occasional traumatic surgeon, and the inference is that he will refer such patients to the specialist.

Part I is a concise and didactic account of general fracture work—diagnosis, pathology, complications and general treatment. Part II gives the detail of treatment of regional fractures and injuries. No attempt is made to enumerate alternatives; the authors give a method—and a good method—for each type. Where operation affords the best chance of a satisfactory result, this is advocated without equivocation. It does not appear, however, that undue stress is laid on operative treatment.

All the little catches, the seemingly minor details which so often spell success or failure, have been remembered. The importance of retaining muscle power and mobility of joints, of active movement, of support for consolidating callus, all receive recognition. The time factor, so often slurred over, is clearly defined—for example, immobilize in

plaster for six weeks, then commence relaxed movements. Proper names are little used and, where they do occur, the necessary explanation is forthcoming. For instance, Leadbetter's test is illustrated. Nothing is more annoying in modern medical literature than to read that the result of Spolinski's test is positive, when one has no idea who or what Spolinski is or was, no idea of what his test might be, and no means of finding out. The drawings and their captions are admirably clear and informative.

Altogether this is a workman's book and the best of its kind that we have seen.

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**Wayfarers in Medicine.** By WILLIAM DOOLIN, M.B., Ch.B., F.R.C.S. (Ireland); 1947. London: William Heinemann (Medical Books), Limited. 8½″ × 5½″, pp. 284, with 39 illustrations. Price: 21s. (Sterling) net.

UNDER the title "Wayfarers in Medicine" Mr. William Doolin, of Dublin, ex-president of the Royal College of Surgeons of Ireland, has collected together the historical essays which he wrote from time to time as editor of *The Irish Journal of Medical Science*. Each of the twenty-seven essays is complete in itself and the series covers a large range of subjects and an even greater period of time, commencing with Imhotep in ancient Egypt and ending with Sir Robert Jones. The author has a delightful literary style, and one is led on from essay to essay.

One of the outstanding chapters is "The Anatomist in Art", in which the pictorial representations of an "Anatomy" are discussed and illustrated, and an excellent critical survey is given of the many anatomical pictures done by the Dutch school.

No less interesting are "Some Old Journeymen Surgeons", "Some Antique Stones", "In the Days of Vesalius" and "A Mediæval Surgeon and his Book". In "The Evolution of Surgery" the author has given us a brief but satisfactory history of surgery. This is an excellent book, well printed and well illustrated, and is certain to have a wide appeal amongst those surgeons interested in the literature and history of medicine.

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## Books Received.

"Endocrinology (Experimental and Clinical). Section 3 of Excerpta Medica." Edited by M. W. Woerdeman, M.D., F.R.A.N.S., A. P. H. A. De Kleyn, M.D., F.R.A.N.S., and W. P. C. Zeeman, M.D.; Volume i, Number 1, 1947. Amsterdam: N.V. Excerpta Medica. 10″ × 6½″, pp. 64. Price: £3 15s. (Sterling) per yearly volume of approximately 600 pages.

"Radiology. Section 14 of Excerpta Medica." Edited by M. W. Woerdeman, M.D., F.R.A.N.S., A. P. H. A. De Kleyn, M.D., F.R.A.N.S., and W. P. C. Zeeman, M.D.; Volume i, Number 1, 1947. Amsterdam: N.V. Excerpta Medica. 10″ × 6½″, pp. 56. Price: £3 15s. (Sterling) per yearly volume of approximately 600 pages.

"Surgery. Section 9 of Excerpta Medica." Edited by M. W. Woerdeman, M.D., F.R.A.N.S., A. P. H. A. De Kleyn, M.D., F.R.A.N.S., and W. P. C. Zeeman, M.D.; Volume i, Number 1, 1947. Amsterdam: N.V. Excerpta Medica. 10″ × 6½″, pp. 120. Price: £6 4s. (Sterling) per yearly volume of approximately 1,000 pages.

"Dermatology and Venereology. Section 13 of Excerpta Medica." Edited by M. W. Woerdeman, M.D., F.R.A.N.S., A. P. H. A. De Kleyn, M.D., F.R.A.N.S., and W. P. C. Zeeman, M.D.; Volume i, Number 1, 1947. Amsterdam: N.V. Excerpta Medica. 10″ × 6½″, pp. 96. Price: £6 4s. (Sterling) per yearly volume of approximately 1,000 pages.

"Modern Audiometric Technique." By B. M. Green. First part of two volumes; 1948. Melbourne: Modern Hearing Aids Proprietary, Limited. 7¼″ × 4¼″, pp. 48, with eight illustrations.

"Pulmonary Tuberculosis." By R. Y. Keers, M.D. (Edin.), F.R.F.P.S. (Glasgow), and B. G. Rigden, M.R.C.S. (England), L.R.C.P. (London); Second Edition; 1946. Edinburgh: E. and S. Livingstone, Limited. 7¼″ × 4¾″, pp. 293, with 124 illustrations. Price: 17s. 6d. (Sterling).

"Textbook of Medicine." By Sir John Conybeare, K.B.E., M.C., D.M. (Oxon), F.R.C.P.; Eighth Edition; 1946. Ednburgh: E. and S. Livingstone, Limited. 8½″ × 5″, pp. 1190, with 23 figures and 29 plates. Price: 30s. (Sterling).

"*Die Hormonalen Aspekte des Fortpflanzungsprozesses.*" By Dr. Jules Samuels; 1946. Amsterdam: Holdert and Company N.V. 9½″ × 6″, pp. 152.

"Endogenous Endocrinotherapy including the Causal Cure of Cancer Compendium." By Dr. Jules Samuels; 1947. Amsterdam: Holdert and Company. 9½″ × 6″, pp. 539, with 30 illustrations.